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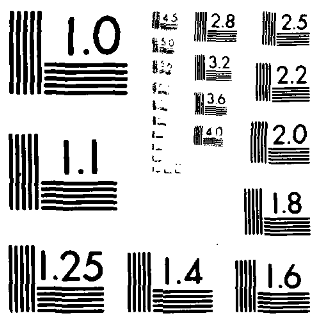

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PROGRAM DESCRIPTION AND USER'S GUIDE FOR ZIPCAP -- A ZERO-ONE INTEGER PROGRAM TO SOLVE MULTIACTIVITY MULTIFACILITY CAPACITY-CONSTRAINED ASSIGNMENT PROBLEMS

by

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Krishan L. Chhabra
Richard M. Soland

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ZIPCAP is a zero-one integer program developed to solve multiactivity multifacility capacity-constrained assignment problems. The objective in such problems is an assignment that minimizes the sum of the variable costs and fixed costs. This document describes ZIPCAP and provides guidelines for its use. Illustrative areas of application, program options, and test problems are included.

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THE GEORGE WASHINGTON UNIVERSITY
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Program in Logistics

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TABLE OF CONTENTS

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1. Introduction

Multiactivity multifacility assignment problems are important because of their practical applications. The objective of such a problem is to minimize the total cost of the system, which includes both variable costs and fixed costs. A problem which has been of recent interest takes into account capacity constraints as well [Gross, Pinkus, and Soland (1979)]. A solution algorithm and a computer program implementing it have been developed for this kind of problem, i.e., for multiactivity multifacility 0-1 assignment problems with capacity constraints.

The development of the solution algorithm and computational test results using the computer program are described in a separate report titled "Solving a Multiactivity Multifacility Capacity-constrained 0-1 Assignment Problem."

This document, on the other hand, provides a description of the

computer program and instructions for its use. It is a FORTRAN program and is named ZIPCAP, an acronym for Zero-one Integer Program to solve multi-activity multifacility Capacity-constrained Assignment Problems.

Section 2 of this document provides a mathematical formulation of the basic problem and examples of application areas. Section 3 includes the computational steps and a program description, whereas Section 4 provides user information including program options and input data specifications. Test problems and output illustrations are covered in Section 5.

2. Problem Formulation

2.1 Basic Problem

The basic problem, called problem (P), is to find x_{ij} and y_k values that:

$$
(P)\quad \begin{cases}
\text{Minimize} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}\, x_{ij} + \sum_{k=1}^{p} b_k y_k & (1) \\
\text{subject to} \quad \sum_{i=1}^{m} x_{ij} = 1 \quad j=1, \ldots, n & (2) \\
\sum_{i=1}^{m} \sum_{j=1}^{n} d_{ijk}\, x_{ij} \leq s_k y_k \quad k=1, \ldots, p & (3) \\
x_{ij}\,,\; y_k = 0 \text{ or } 1 \quad \text{for all } i,\ j,\ k & (4)
\end{cases}
$$

where m , n , and p represent the number of designs, activities, and facilities respectively; and i , j , k are the corresponding indices.

The parameters are interpreted as follows:

a_{ij} = variable cost of activity j using design i ,

b_k = fixed cost of facility k ,

s_k = capacity available at facility k , and

d_{ijk} = capacity required at facility k for activity j when activity j uses design i .

The decision variables are:

x_{ij} = 1 if activity j uses design i ,
= 0 otherwise.

y_k = 1 if facility k is used ,
= 0 otherwise.

Simply stated, in problem (P) one seeks to minimize the sum of variable and fixed costs subject to constraint set (2) that each activity be assigned a single design and subject to constraint set (3) that the capacity constraints imposed by the facility capacities are satisfied.

Problem (P) has $mn+p$ 0-1 variables and $n+p$ constraints.

2.2 Key Elements

The key elements in problem (P) are activities, facilities, designs, variable costs, and fixed costs. In general, these can be defined as follows.

- Activity -- a type of component, product or item under consideration.

- Facility -- an installation or location where activities can be served or serviced.

- Design -- a meaningful configuration of facilities along with a meaningful strategy for using them. For example, if there are four facilities 1, 2, 3 and 4, a design may include facilities 1, 2 and 4, whereas another design may include facility 2 only.

- Variable Cost -- the cost associated with a particular activity being assigned to a particular design.

- Fixed Cost -- the cost associated with a facility (such as part of its purchase, operation and maintenance cost) that is independent of the activities served at that facility.

2.3 Areas of Application

The computer program ZIPCAP is designed to solve a problem that can be formulated as problem (P). The formulation applies to existing as well as to proposed facilities. In other words, it is useful for a situation where the decision may be to delete some of the existing facilities, as well as for a situation involving a choice among proposed facilities (or locations).

Table 1 includes examples of areas where this formulation can be applied. Within each application area, activities and facilities are identified. The implications of designs, variable costs and fixed costs are apparent.

3. Computational Procedure and Program Description

The procedure to solve problem (P) basically involves branch and bound [Geoffrion and Marsten (1972)], and Lagrangean relaxation

Table 1

EXAMPLES OF APPLICATION AREAS

Area of Application	Activities	Facilities
1. Design of multi-echelon inventory systems*	Items to be stocked	Warehouses (Comprising different levels or echelons, e.g., central, regional, and local warehouses)
2. Assignment of repairable components**	Major components of a unit, e.g., components of an aircraft, a ship, a piece of machinery	Repair depots
3. Design of training programs	Training program categories or occupational classifications	Training schools
4. Location of facilities***	Types of services, e.g., health-care services	Buildings or installations, e.g., health-care centers

*Gross, Pinkus, and Soland (1979)

**Gross and Pinkus (1979)

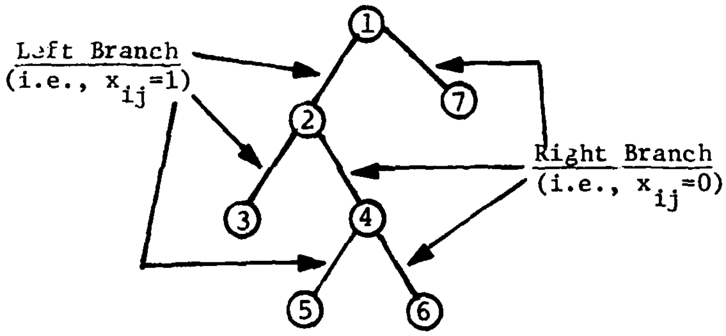
***Pinkus, Gross, and Soland (1973)

[Geoffrion (1974)]. In addition certain heuristics are used for branching, and to exclude infeasible assignments.

Branching is done on the x_{ij} variables by setting them equal to 1 or 0. The branching commences by setting a variable equal to 1 and moving to the left-branch node. When backtracking, the corresponding variable is set equal to 0 and we move to the right-branch node (if the right-branch has not yet been explored). Figure 1 illustrates a branching tree.

Figure 1

Tree Branching Illustration



Node (1) is the root node and also parent node for nodes (2) and (7)

Node (2) is parent node for nodes (3) and (4), etc.

The x_{ij} variables which have been set equal to 1 or 0 at any given node are termed <u>fixed variables</u>, and the remaining ones are termed <u>free variables</u>.

3.1 Computational Steps

Figure 2 presents a simplified flow diagram, showing the

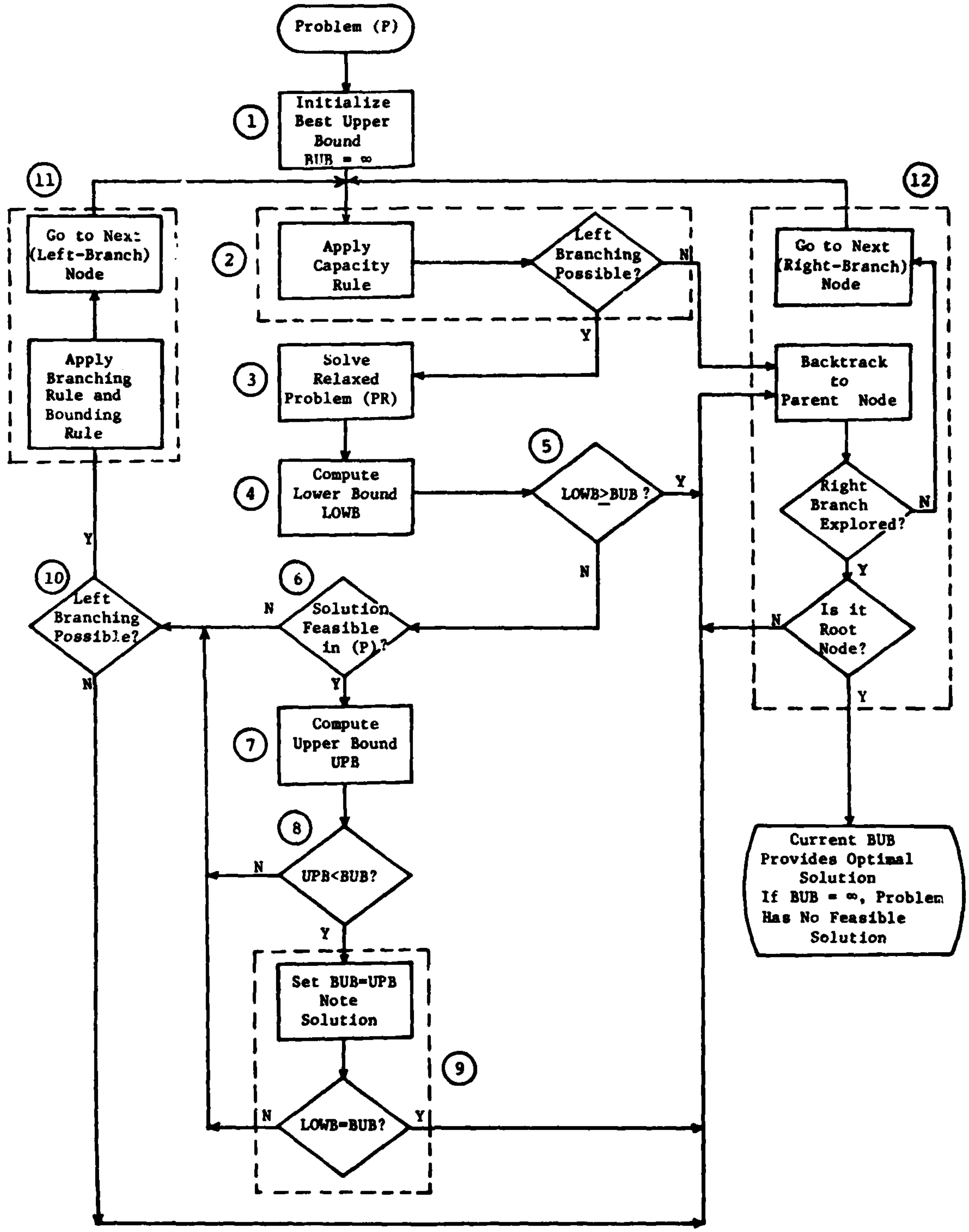


Figure 2

Simplified Flow Diagram Showing Computational Steps

computational steps of the computer program. Following is a description of these steps.

Step 1. Initialize by setting best upper bound (BUB) equal to a large value and the node number to 1.

Step 2. Apply the capacity rule to exclude infeasible assignments prior to solving the relaxed problem.

Exclude a free x_{ij} if, for any facility k and activity j,

$$\left(d_{ijk} - \min_j d_{ijk}\right) > \left(s_k - \Sigma_j \min_j d_{ijk}\right).$$

If an x_{ij} is already fixed as 1, the corresponding d_{ijk} replaces $\min_j d_{ijk}$.

If $\Sigma_j \min_j d_{ijk} > s_k$, then backtrack, i.e., go to step 12.

Step 3. Solve the relaxed problem (PR), i.e.,

$$(\text{PR}) \begin{cases} \text{Minimize} & \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \; x_{ij} \\ \text{subject to} & \sum_{i=1}^{m} x_{ij} = 1 \quad j=1, \cdots, n, \\ & x_{ij} = 0 \text{ or } 1 \text{ for all } i, j, \end{cases}$$

where $c_{ij} = a_{ij} + \sum_{k=1}^{p} b_k \left(1 - \delta_k\right)\left(d_{ijk}/s_k\right)$,

$$\delta_k = 1 \text{ if } \sum_{\substack{i \\ \text{such that} \\ x_{ij} \text{ is fixed}}} \sum_{j} x_{ij} \; e_{ik} > C,$$

$$= 0 \text{ otherwise, and}$$

$$e_{ik} = 1 \text{ if design } i \text{ uses facility } k\,,$$
$$= 0 \text{ otherwise.}$$

<u>Step 4</u>. Lower bound (LOWB) is the sum of the optimal solution value of problem (PR) and the fixed cost FC. FC is the cost of the facilities forced into the solution because of the x_{ij} variables fixed as 1:

$$FC = \sum_{k=1}^{p} \delta_k b_k$$

<u>Step 5</u>. Compare lower bound with best upper bound. If LOWB $\geq$ BUB , go to step 12.

<u>Step 6</u>. Check if the solution of problem (PR) obtained in step 3 satisfies the capacity constraints of problem (P) , i.e.,

$$\sum_{i=1}^{m} \sum_{j=1}^{n} d_{ijk} \; x_{ij} \leq s_k y_k \qquad k=1, \ldots, p,$$

where $y_k = 1$ if $\Sigma_i \; \Sigma_j \; d_{ijk} \; x_{ij} > 0$,

$= 0$ otherwise

If the capacity constraints are not satisfied, go to step 10.

<u>Step 7</u>. Compute upper bound (UPB) , i.e.,

$$UPB = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} \; x_{ij} + \sum_{k=1}^{p} b_k y_k$$

Step 8. Compare upper bound with best upper bound. If UPB $\geq$ BUB, go to step 10.

Step 9. Retain UPB as BUB , i.e., set BUB = UPB and note the corresponding solution comprising x_{ij} and y_k variables.

If LOWB equals BUB (same as UPB in this case), go to step 12.

Step 10 If an x_{ij} variable has been fixed as 1 for each of the n activities, then go to step 12.

Step 11. Select an x_{ij} variable for branching to the left node. The choice of the branching variable depends on the c_{ij} values and is such that the corresponding x_{ij} , if perturbed, has the maximum impact on the optimal value of problem (PR). That is, for each j , obtain $D_j = c_{2j} - c_{1j}$ where c_{2j} is the second smallest permissible and c_{1j} is the smallest permissible c_{ij} value in column j .

A c_{ij} value is considered permissible if it does not correspond to an activity j having x_{ij} variable fixed as 1 , or to an x_{ij} variable fixed as 0 . The x_{ij} variables can be fixed as 1 or 0 because of the branching rule, backtracking, and/or use of the capacity rule. Further, x_{ij} may be fixed as 0 because of the bounding rule, i.e., if $\left(c_{ij} - c_{1j}\right) > \left(\text{BUB} - \text{LOWB}\right)$.
The x_{ij} variable selected has the maximum value of D_j and has $c_{ij} = c_{1j}$.

Set the selected x_{ij} variable to 1 . Increase the node number by one, and go to step 2.

Step 12. Backtracking continues until a node is reached for which

the right branch has not been explored. Set the corresponding x_{ij} variable to 0 . Increase the node number by one, and go to step 2.

If no such node is found, it implies that the root node has been reached, and the procedure terminates.

The current BUB and the solution obtained in step 9 provide the optimal solution and its value. If BUB happens to be the initial value, the problem does not have a feasible solution, i.e., the capacity constraints cannot be satisfied.

3.2 Computer Program

The computer program ZIPCAP is written in FORTRAN IV. It is based on the flow diagram and the computational steps described in the preceding paragraphs.

Appendix A provides a listing of the program. Extensive use of comment cards provides details within each computational step.

A dictionary of the symbolic names used in the program listing is provided in Appendix B.

The program has been developed and tested on an IBM 3031 at The George Washington University.* The only internally supplied subroutine used by the program is TIMET from the PIJ Library. This subroutine provides the elapsed time for program execution and excludes the time to read and write the input and output.

---

*IBM 3031 CPU with 3 million Bytes Real Memory. Operating System OS/VS1 Release 6.7. Various compilers including FORTRAN levels G 1 to 6 and H 1 to 6.

The program comprising about 480 lines is currently dimensioned for a problem size of 35 designs (m) , 35 activities (n) and 30 facilities (p) . The user capacity required to execute this program is 346 K bytes. The functional relationship between the dimensions of the arrays and the storage requirement is given by

$$f\ (m\ ,\ n\ ,\ p) = 4\left[(p+4)mn + (m+5)p + 9n\right] \text{ bytes.}$$

Thus the program size to execute a problem has two components: one, due to the program itself, comprises 173 K bytes, and the other, dependent on the dimensions of the arrays, is given by the above functional relationship.

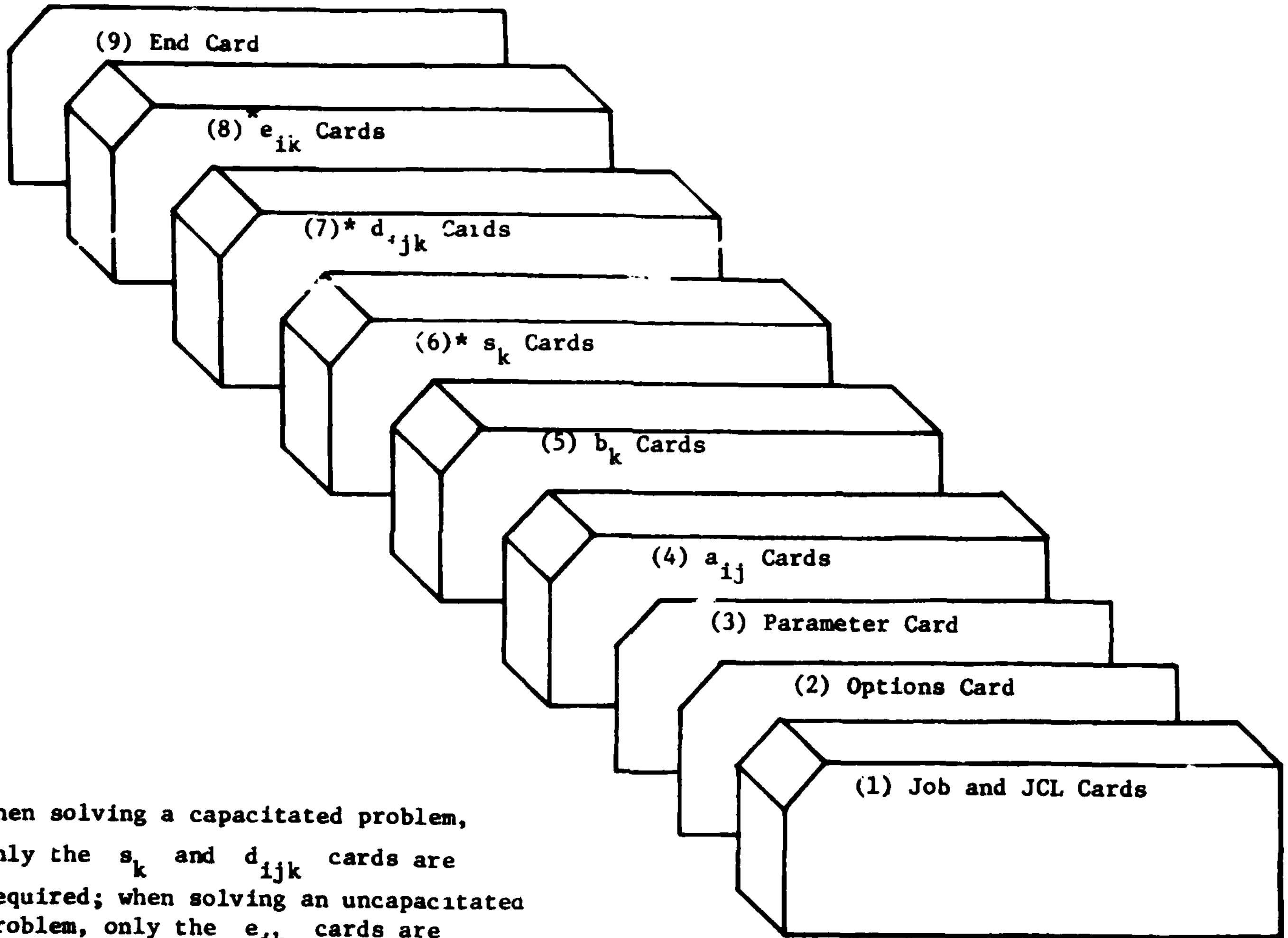
4. User Information

ZIPCAP is designed to solve a multiactivity multifacility capacity-constrained 0-1 assignment problem having formulation (P) . Such a problem is referred to as "capacitated" because the optimal solution must satisfy the capacity constraints. However, the program can be used in a situation where the capacity constraints are not applicable, in other words, for an "uncapacitated" problem. The program, in this case, will generate the necessary information to conform to formulation (P) .

Figure 3 presents a schematic diagram of the deck structure for using ZIPCAP. The cards include both the job control cards and the input data cards required to solve a problem.

Following is a detailed description of these cards (in the same order as presented in Figure 3); it provides the necessary coding information.

(1) Job and JCL Cards: Figures 4A and 4B show two alternatives for the use of JCL cards.



*When solving a capacitated problem, only the s_k and d_{ijk} cards are required; when solving an uncapacitated problem, only the e_{ik} cards are required.

Figure 3

ZIPCAP Data Structure

IBM FORTRAN Coding Form

PROGRAM | PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH

FORTRAN STATEMENT

```
// STANDARD JØB CARD
// EXEC FØRG2
//FØRT.SYSIN DD *

  (SØURCE PRØGRAM)

//GØ.SYSLIB DD                            JCL CARDS FØR
// DD DSN=GWU.PL1XLIB,DISP=SHR            TIMET SUBRØUTINE
//GØ.SYSIN DD *

  (DATA CARDS)

//
```

Figure 4A

Job and JCL Cards -- Alternative I

IBM FORTRAN Coding Form

FORTRAN STATEMENT

```
// STANDARD JØB CARD
// EXEC FØRG3, DSN='YØUR LIBRARY', PRØG=ZIPCAP
// FØRT.SYSIN DD *

   (SØURCE PRØGRAM)

//
```

Step 1: Compile and Store Procedure

```
// STANDARD JØB CARD
// EXEC FØRG6,DSN='YØUR LIBRARY',PRØG=ZIPCAP
//GØ.SYSLIB DD                                   } JCL CARDS FØR
// DD DSN=GWU.PLIXLIB,DISP=SHR                   } TIMET SUBRØUTINE
//GØ.SYSIN DD *

   (DATA CARDS)

//
```

Step 2: Load and Go Procedure

Figure 4B

Job and JCL Cards -- Alternative II

Alternative I uses the source program for the compilation and execution procedure. In Alternative II, the program is first compiled and stored, and thereafter, for a given problem, only the execution is necessary.

The program uses the TIMET subroutine from the PL1 Library in order to record the elapsed time. This time includes only the execution time of the program and excludes the time needed to read the input and to write the output. The JCL cards needed for this purpose are identified in Figures 4A and 4B . If this subroutine is not available, the corresponding JCL cards are not required. In that case the appropriate source program cards should also be removed. (These cards are identified in the program listing in Appendix A.)

(2) Options Card

The options card is the first input data card and is described in Table 2.

(3) Parameter Card

Table 3 describes the parameter card.

Table 3
THE PARAMETER CARD

Columns	Format	Name	Definition
1-5	I5	M	Number of designs (m)
6-10	I5	N	Number of activities (n)
11-15	I5	P	Number of facilities(p)

Table 2

OPTIONS CARD

Columns	Format	Name	Value and Definition	Remarks
1	I1	IINPT	1 if input listing desired 0 otherwise	Input listing includes: - parameters m , n , p - a_{ij} , b_k , s_k, d_{ijk} , and e_{ik}
2	I1	ICAPR	1 if capacity rule to be used 0 otherwise	When solving a capacitated problem (i.e., where capacity constraints are applicable), set ICAPR=1; for an uncapacitated problem, it should be set to 0.
3	I1	ISTEP	0 if listing of intermediate steps not desired 1 if summary of intermediate steps desired 2 if detailed intermediate steps desired	. Summary of intermediate steps includes, for each node, node number, lower bound, upper bound (if applicable), best upper bound, and branching variable. (This information is sufficient to construct a branch-and-bound tree.) . Detailed intermediate steps list every computational step at every node. This option is useful only when changing/debugging the program. . Even with ISTEP = 0, the output includes the total number of nodes explored.

Continued

Table 2
(Continued)

Columns	Format	Name	Value and Definition	Remarks
4	I1	IUNCAP	0 if solving a capacitated problem 1 if solving an uncapacitated problem	for IUNCAP=0, ICAPR should be 1, and for IUNCAP=1, ICAPR should be 0. (for IUNCAP=1, if ICAPR=1, the program overrides it and sets ICAPR=0)
5-10	F6.5	EPS	A fractional value if a sub-optimal solution is acceptable. This value should be zero if an optimal solution is desired.	EPS = 0.002 implies that the resulting solution may be suboptimal, but is guaranteed to have a value within 0.2% of the optimal value.
11-20	F10.3	ET	Elapsed time in seconds, if specified, at which the node and bounds information is printed.	. Specifying ET is useful in a case where ISTEP = 0 and the program terminates before reaching the final solution. . When applicable, the information printed includes: - the node being explored at the specified time - the best upper bound, the corresponding solution, and the node at which this solution was found - detailed steps for the node being explored, by assuming ISTEP=2 . The above information is useful in assessing the extent of the branch-and-bound tree explored until time ET. . This option uses the TIMET subroutine

(4) to (8) Other Input Data Cards

Table 4 describes the cards for the variable costs a_{ij}, the fixed costs b_k, the capacity availabilities s_k, and the capacity usage values d_{ijk}. However, if solving an uncapacitated problem, i.e., where capacity constraints are not active, the facility-design values e_{ik} are required as input data instead of the s_k and d_{ijk} values.

The input data values for a_{ij}, b_k, s_k, and d_{ijk} are required in integer format. Any real-valued data can be converted into integer values by scaling, and the optimal solution reconverted to real values later. For example, real-valued data of 215.35, 116.50, ..., 180.61 can be treated as 21535, 11650, ..., 18061; and an optimal value of 584230 obtained from the program would correspond to 5842.30.

(9) End Card

This is the usual end card following input data cards. It contains '//' in the first two columns.

5. Test Problems and Output Illustrations

5.1 Test Problem 1

5.1.1 Problem formulation (stated for ease of reference)

The problem is to find x_{ij} and y_k variables that

Table 4

OTHER INPUT DATA CARDS

Columns	Format	Name	Definition	Remarks
1-10, 11-20, 21-30, etc.	8I10	A(I,J)	Variable cost of activity j using design i	The order of the input data a_{ij} is a_{11} , a_{21} , ..., a_{m1} ; a_{12} , a_{22} , ..., a_{m2} ; ..., a_{1n} , a_{2n} , ..., a_{mn}
1-10, 11-20, 21-30, etc.	8I10	B(K)	Fixed cost of facility k	The order for the b_k is b_1 , b_2 , ..., b_p
1-10, 11-20, 21-30, etc.	8I10	S(K)	Capacity available at facility k	. The order for the s_k is s_1 , s_2 , ..., s_p . This input is required when solving a capacitated problem only, i.e., for IUNCAP=0. For an uncapacitated problem, i.e., for IUNCAP=1, this information is generated by the program.

Continued

Table 4
(Continued)

Columns	Format	Name	Definition	Remarks
1-10, 11-20, 21-30, etc.	8I10	D(I,J,K)	Capacity required at facility k for activity j when activity j uses design i. A d_{ijk} value is positive if design i uses facility k; otherwise it is 0.	. The order of input data is all d_{ijk} for $k=1$, then all d_{ijk} for $k=2$, etc., starting on a new card when the value of k changes. . The order of input for a facility k is $d_{11k}, d_{21k}, \ldots, d_{m1k}$; $d_{12k}, d_{22k}, \ldots, d_{m2k}$; ....; $d_{1nk}, d_{2nk}, \ldots, d_{mnk}$. . This input, similar to s_k, is required for capacitated problems only, i.e., for IUNCAP=0. This information is generated by the program for an uncapacitated problem, i.e., for IUNCAP=1.

Continued

Table 4
(Continued)

Columns	Format	Name	Definition	Remarks
1,2,3,...	80I1	E(I,K)	$e_{ik} = 1$ if design i uses facility k $= 0$ otherwise	. The order of input for the e_{ik} is $e_{11}, e_{21}, \ldots, e_{m1}$; $e_{12}, e_{22}, \ldots, e_{m2}; \ldots, e_{1p}, e_{2p}, \ldots, e_{mp}$. . This input is required when solving an uncapacitated problem only, i.e., for IUNCAP=1. The program, then generates d_{ijk} and s_k as follows: $d_{ijk} = 1$ for all j if $e_{ik} = 1$ $= 0$ for all j if $e_{ik} = 0$ $s_k = n$ for all j . e_{ik} is generated by the program for a capacitated problem, as follows: $e_{ik} = 1$ if $\sum_j d_{ijk}$ is positive (>0) $= 0$ otherwise

$$
(P)\begin{cases}
\text{Minimize} & \sum_{j=1}^{n}\sum_{i=1}^{m} a_{ij}\, x_{ij} + \sum_{k=1}^{p} b_k y_k & (1)\\
\text{subject to} & \sum_{i=1}^{m} x_{ij} = 1 \quad j=1,\cdot\cdot,n & (2)\\
& \sum_{j=1}^{n}\sum_{i=1}^{m} d_{ijk}\, x_{ij} \le s_k y_k \quad k=1,..,p & (3)\\
& x_{ij}\,,\ y_k = 0 \text{ or } 1, & (4)
\end{cases}
$$

where $m = 3$, $n = 4$, $p = 5$.

The a_{ij} values are:

		j = 1	2	3	4
i	1	9,847	15,718	4,450	8,925
	2	10,192	10,542	4,422	8,118
	3	11,019	9,750	4,609	8,337

$b_1 = 1750$ $b_2 = 2000$ $b_3 = 1750$ $b_4 = 1350$ $b_5 = 1000$

$s_1 = 400$ $s_2 = 400$ $s_3 = 1000$ $s_4 = 400$ $s_5 = 400$

The d_{ijk} values are as follows:

k=1		j = 1	2	3	4
i	1	0	0	0	0
	2	186	60	261	148
	3	154	38	175	100

k=2

i \ j	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	154	38	175	100

k=3

i \ j	1	2	3	4
1	525	144	1,011	396
2	186	60	261	148
3	154	38	175	100

k=4

i \ j	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	154	38	175	100

k=5

i \ j	1	2	3	4
1	0	0	0	0
2	186	60	261	148
3	154	38	175	100

5.1.2 Coded Input: Figure 5 shows the coded information for test problem 1. Various segments in this figure are numbered in parentheses to correspond to the deck structure of Figure 3.

IBM

FORTRAN Coding Form

GX28-7327-6 U/M 050
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PROGRAM		PUNCHING INSTRUCTIONS	GRAPHIC		PAGE OF
PROGRAMMER	DATE		PUNCH		CARD ELECTRO NUMBER

```
C STATEMENT NUMBER | CONT | FORTRAN STATEMENT                                              | IDENTIFICATION SEQUENCE
//  STANDARD JΦB CARD
//  EXEC FΦRG6,DSN='YΦUR LIBRARY',PRΦG=ZIPCAP
//GΦ.SYSLIB DD                                                                               (1)
//  DD  DSN=GWU.PL1XLIB,DISP=SHR
//GΦ.SYSIN DD *
111                                                                                          (2)
    3      4    5                                                                            (3)
        9847   10192   11019   15718   10542    9750    4450    4422
        4609    8925    8118    8337                                                         (4)
        1750    2000    1750    1350    1000                                                 (5)
         400     400    1000     400     400                                                 (6)
           0     186     154       0      60      38       0     261
         175       0     148     100
           0       0     154       0       0      38       0       0
         175       0       0     100
         525     186     154     144      60      38    1011     261                         (7)
         175     346     148     100
           0       0     154       0       0      38       0       0
         175       0       0     100
           0     186     154       0      60      38       0     261
         175       0     148     100
//                                                                                           (9)
```

Figure 5

Coded Input Data for Test Problem 1

5.1.3 Annotated Output: The computer output for this test problem is presented in Appendix C. Most segments of this output are self-explanatory. The order of these segments is lettered in circles as follows:

(a) Options selected -- information given on options card

(b) m, n, and p -- information from parameter card. This segment is printed if the option IINPT=1

(c) Other input data, i.e., a_{ij} , b_k , s_k and d_{ijk} for a capacitated problem; and e_{ik} as generated by the program. For an uncapacitated problem, input data a_{ij} , b_k , and e_{ik} ; and s_k and d_{ijk} as generated by the program. This segment is printed if the option IINPT=1

(d) Intermediate steps' display, depending on the value of the option ISTEP. No display for ISTEP=0, summary for ISTEP=1, and detailed steps for ISTEP=2

(e) Elapsed time in seconds to execute the program, excluding the time to read the input data and to write the input and output. It includes the time to print intermediate steps if option ISTEP=1 or 2

(f) Total number of nodes explored for the problem solved

(g) Optimal solution showing the x_{ij} variables with value 1, y_k variables with value 1 or 0, and the value of the objective function. If the problem does not have a feasible solution, this segment prints "Problem does not have a feasible solution because the capacity constraints cannot be satisfied."

The node and bounds information at a specified time is displayed only if option KT is assigned a particular value.

5.2 Test Problem 2

This is a capacitated problem having 5 designs, 4 activities and 8 facilities.

The problem formulation and coded input are similar to that of test problem 1.

The annotated output (which includes the listing of input data) is presented in Appendix D. The annotations are the same as those already described for test problem 1. Note that the options selected include ISTEP=0, hence no intermediate steps; and EPS=0.002, implying that the solution may be suboptimal within + 0.2% .

5.3 Test Problem 3

Although ZIPCAP is designed for capacitated problems, it may be used to solve uncapacitated problems as a special case. For demonstration, this test problem is uncapacitated, having 10 designs, 8 activities, and 8 facilities. The input data include the options card, the parameter card, input data values for a_{ij} , b_k , and e_{ik} . The program generates the d_{ijk} and s_k values.

Appendix E shows the annotated output for this problem. Note that the options selected include IINPT=1, hence the data listing; ISTEP=0, therefore no intermediate steps; ICAPR=0 and IUNCAP=1 being an uncapacitated problem. Note that option ET has been specified a value of 30.0 . Thus, if the optimal solution was not reached within 30 seconds, the node and bounds information at time ET would have been displayed.

REFERENCES

[1] GEOFFRION, A.M. (1974). Lagrangean relaxation for integer programming. Mathematical Programming Study 2 82-114.

[2] GEOFFRION, A.M., and R.E. MARSTEN (1972). Integer programming algorithms: a framework and state-of-the-art survey. Management Science 18 465-491.

[3] GROSS, D. and C. E. PINKUS (1979). Designing a support system for repairable items. Computers and Operations Research 6 59-68.

[4] GROSS, D., C.E. PINKUS, and R. M. SOLAND (1979). Designing a multi-product multi-echelon inventory system. Technical Paper Serial T-392. Program in Logistics, Institute for Management Science and Engineering, The George Washington University.

[5] PINKUS, C.E. (1975). Optimal design of multi-product multi-echelon inventory systems. Decision Sciences 6 492-507.

[6] PINKUS, C.E., D. GROSS, and R. M. SOLAND (1973). Optimal design of multiactivity multifacility systems by branch and bound. Operations Research 21 270-283.

APPENDIX A

ZIPCAP LISTING

```
FORTRAN IV G LEVEL  21                    MAIN               DATE = 80206          14/35/07

                C                 ZIPCAP, A ZERO-ONE INTEGER PROGRAM IS DESIGNED       00000010
                C                 TO SOLVE MULTIACTIVITY MULTIFACILITY CAPACITY-       00000015
                C                 CONSTRAINED PROBLEMS HAVING VARIABLE AND FIXED       00000020
                C                 COSTS. IT ALSO SOLVES UNCAPACITATED PROBLEMS AS A    00000030
                C                 SPECIAL CASE                                         00000040
  0001                INTEGER   D(35,35,30), A(35,35), CX(35,35), E(35,30),            00000050
                     1          B(30), BSOLX(35), BSOLY(30), FLB(30),FIX(35),FIXI(35), 00000060
                     2          FUB(30), S(30), SOLX(35), STX(1225)                    00000070
  0002                REAL                MINC(35), NMINC(35)                          00000080
  0003                DIMENSION C(35,35), DIFBR(35), KT2(35), MIND(35)                 00000090
  0004                INTEGER   BRO, BR1, FC, FCUB, P                                  00000110
  0005                REAL      LOWB, MAXDIF, MINSC                                    00000120
                C     **************OPTIONS AVAILABLE: IINPT, ICAPP, ISTEP, IUNCAP,EPS 00000130
                C                 IINPT=1 IF INPUT LISTING DESIRED; 0 OTHERWISE        00000140
                C                 ICAPR=1 IF CAPACITY RULE TO BE USED; 0 OTHERWISE     00000150
                C                 ISTEP=0 IF LISTING OF INTERMEDIATE STEPS             00000160
                C                 NOT DESIRED. ISTEP=1 IF SUMMARY OF BRANCH &          00000170
                C                 BOUND NODES DESIRED. ISTEP=2 IF DETAILED             00000180
                C                 LISTING OF INTERMEDIATE STEPS DESIRED.               00000190
                C                 IUNCAP=1 IF SOLVING AN UNCAPACITATED PROBLEM,        00000200
                C                 0 OTHERWISE.                                         00000210
                C                 EPS= A FRACTIONAL VALUE IF SUBOPTIMAL                00000220
                C                 SOLUTION DESIRED, E.G., EPSILON AS 0.005             00000230
                C                 IMPLIES SOLUTION TO BE WITHIN +0.5 PERCENT           00000240
                C                 OF THE OPTIMAL SOLUTION. EPS=0.0 IF OPTIMAL          00000250
                C                 SOLUTION DESIRED.                                    00000253
                C                 ET= ELAPSED TIME IN SECONDS, IF SPECIFIED, AT        00000256
                C                 WHICH THE NODE AND BOUNDS RELATED INFORMATION        00000260
                C                 IS PRINTED. THIS IS USEFUL IN A SITUATION IF         00000263
                C                 ISTEP=0 AND THE PROGRAM TERMINATES BEFORE            00000266
                C                 REACHING THE FINAL SOLUTION.                         00000270
                C     **************READ INPUT DATA*********************************** 00000273
  0006                READ 10, IINPT, ICAPR, ISTEP, IUNCAP, EPS, ET                    00000280
  0007             10 FORMAT (4I1, F6.5, F10.3)                                        00000290
                C                 M= NUMBER OF DESIGNS                                 00000300
                C                 N= NUMBER OF ACTIVITIES                              00000310
                C                 P= NUMBER OF FACILITIES                              00000320
  0008                READ 20,M,N,P                                                    00000330
  0009             20 FORMAT (3I5)                                                     00000340
                C                 A(I,J): VARIABLE COST MATRIX                         00000350
  0010                READ 30,  ((A(I,J), I=1,M),J=1,N)                                00000360
  0011             30 FORMAT   (8I10)                                                  00000370
                C                 B(K): FIXED COST VECTOR                              00000380
  0012                READ 30, (B(K),K=1,P)                                            00000390
  0013                IF (IUNCAP.EQ.1) GO TO 40                                        00000400
                C                 S(K): CAPACITY LIMIT VECTOR; REQUIRED ONLY           00000410
                C                 IF IUNCAP=0                                          00000420
  0014                READ 30, (S(K),K=1,P)                                            00000430
                C                 D(I,J,K): CAPACITY USAGE MATRIX; REQUIRED            00000440
                C                 ONLY IF IUNCAP=0                                     00000450
  0015                DO 32 K=1,P                                                      00000460
  0016                READ 30,((D(I,J,K), I=1,M),J=1,N)                                00000470
  0017             32 CONTINUE                                                         00000480
  0018                DO 37 K=1,P                                                      00000490
  0019                DO 37 I=1,M                                                      00000500
  0020                   IF (D(I,1,K).EQ.0) GO TO 35                                   00000510
  0021                   E(I,K)=1                                                      00000520
  0022                   GO TO 37                                                      00000530
```

FORTRAN IV G LEVEL 21 MAIN DATE = 80206 14/35/07

```
      35    E(I,K)=0
      37 CONTINUE
         GO TO 90
C                       E(I,K): DESIGN-FACILITY MATRIX; REQUIRED ONLY
C                       IF IUNCAP=1
      40 READ 45,((E(I,K),I=1,M),K=1,P)
      45 FORMAT  (80I1)
         DO 80 K=1,P
            S(K)=N
         DO 75 I=1,M
            IF (E(I,K).EQ.1) GO TO 65
         DO 60 J=1,N
            D(I,J,K)=0
      60 CONTINUE
            GO TO 75
      65 DO 70 J=1,N
            D(I,J,K)=1
      70 CONTINUE
      75 CONTINUE
      80 CONTINUE
C        **************PRINT INPUT DATA*********************************
      90 PRINT 95, IINPT,  ICAPR, ISTEP, IUNCAP, EPS, ET
      95 FORMAT ( '1',' OPTIONS SELECTED :  IINPT=',I1,
        1        '  ICAPR=',I1, '  ISTEP=',I1, '  IUNCAP=',I1,
        2        '  EPS=',F8.5, '  ET=', F10.3///)
         IF (IINPT.EQ.0) GO TO 168
         PRINT  100,M,N,P
     100 FORMAT ('0', T55, 'INPUT DATA',/1X, T55, '---------- ----------',//////1X,
        1T41, 'NUMBER OF DESIGNS (M)=', 4X,I4//1X,T41,
        2'NUMBER OF ACTIVITIES (N)=', 1X,I4//1X, T41,
        3'NUMBER OF FACILITIES (P)=',1X, I4///)
         PRINT  105
     105 FORMAT ( 4X,    'VARIABLE COST MATRIX  A(I,J)',/4X,
        1'-----------------------------',/)
         DO  110 I=1,M
     110 PRINT 115, I, (A(I,J),J=1,N)
     115 FORMAT ('0', T6, 'I=', I3, 4X,8I13, 4(/, 14X,8I13))
         PRINT 120
     120 FORMAT('0',//4X,'FIXED COST VECTOR  B(K)',/4X,
        1'-----------------------',      /)
         PRINT 122, (B(K),K=1,P)
     122 FORMAT ('0', T15, 8I13, 3(/, 14X,8I13))
         PRINT  125
     125 FORMAT('0',//4X,'CAPACITY LIMIT VECTOR  S(K)',/4X,
        1'---------------------------',  /)
         PRINT 128, (S(K),K=1,P)
     128 FORMAT ('0', T15, 8I13, 3(/, 14X,8I13))
         PRINT 130
     130 FORMAT('0',//4X, 'CAPACITY USAGE MATRIX  D(I,J,K)',/4X,
        1'-------------------------------',/)
         DO  150 K=1,P
         PRINT  135,K
     135 FORMAT ('0',//5X,'K=',I3/)
         DO  145 I=1,M
         PRINT  140,I,(D(I,J,K), J=1,N)
     140 FORMAT ('0', T6, 'I=', I3, 4X,8I13, 4(/, 14X,8I13))
     145 CONTINUE
     150 CONTINUE
```

```
FORTRAN IV G LEVEL  21                    MAIN                DATE = 80206          14/35/07
 0069              PRINT 155                                                        00001120
 0070          155 FORMAT('0',//4X,'DESIGN-FACILITY MATRIX E(I,K)',/4X,            00001130
              1'------------------------------',/)                                  00001140
 0071              DO 160  I=1,M                                                    00001150
 0072              PRINT 158, I, (E(I,K),K=1,P)                                     00001160
 0073          158 FORMAT ('0', T6, 'I=', I3, 4X,8I13, 3(/, 14X,8I13))             00001170
 0074          160 CONTINUE                                                         00001180
 0075          168 IF (ISTEP.EQ.0) GO TO 190                                        00001190
 0076              IF (ISTEP.EQ.1) GO TO 175                                        00001200
 0077              PRINT 170                                                        00001210
 0078          170 FORMAT ('0',///55X,'DETAILED LISTING OF STEPS',/)               00001220
 0079              GO TO 190                                                        00001230
 0080          175 PRINT 180                                                        00001240
 0081          180 FORMAT ('0',///55X,'SUMMARY OF STEPS',/)                        00001250
             C     **************INITIALIZE***************************************** 00001260
 0082          190 BUB=9999999.                                                     00001270
 0083              BUBS= BUB/ (1.0+EPS)                                             00001280
 0084              NSX=0                                                            00001290
 0085              NOD=1                                                            00001310
 0086              IBNOD=1                                                          00001315
 0087              INFT=0                                                           00001320*
 0088              INSET=0                                                          00001330*
 0089              DO 205 J=1,N                                                     00001390
 0090                 FIX(J)=0                                                      00001400
 0091                 KT2(J)=0                                                      00001410
 0092              DO 205 I=1,M                                                     00001420
 0093                 CX(I,J)=0                                                     00001430
 0094          205 CONTINUE                                                         00001433
 0095              LQ1=0                                                            00001436
 0096              LQ2=0                                                            00001440
 0097              LR2=0                                                            00001443
 0098              CALL TIMET(ITO)                                                  00001445*
 0099              IF(NSX.EQ.0) GO TO 283                                           00001447
             C                    CX(I,J) CONTAINS FIXED AND FREE X(I,J) VARIABLES.   00001450
             C                    STX(INS) CONTAINS FIXED X(I,J) VARIABLES.          00001460
             C                    CX(I,J) AND STX(INS) ARE UPDATED BY THE CAPACITY   00001480
             C                    RULE, THE BOUNDING RULE, AND THE RULE FOR          00001490
             C                    BRANCHING AND BACKTRACKING.                        00001500
             C                    IN CX(I,J) A FIXED VARIABLE IS RECORDED AS 1 OR    00001505
             C                    2, AND A FREE VARIABLE AS 0.                       00001510
             C                    A VALUE OF 1 IMPLIES THAT THAT PARTICULAR VARIABLE 00001515
             C                    IS FIXED, AND FIX(J) IS SET EQUAL TO 1 IMPLYING    00001520
             C                    THAT COLUMN J HAS A FIXED VARIABLE OF VALUE 1.     00001525
             C                    A VALUE OF 2 IMPLIES THAT THAT PARTICULAR VARIABLE 00001530
             C                    SHOULD NOT BE CONSIDERED FOR CURRENT COMPUTATIONS. 00001535
             C                    AN X(I,J) RECORDED IN CX(I,J) AS 1 DUE TO THE      00001540
             C                    BRANCHING RULE IS RECORDED IN STX(INS) AS X*100+J. 00001545
             C                    AN X(I,J) RECORDED IN CX(I,J) AS 1 DUE TO THE      00001550
             C                    CAPACITY RULE OR THE BOUNDING RULE IS RECORDED IN  00001555
             C                    STX(INS) AS (X*100+J)+1000000.                     00001560
             C                    AN X(I,J) RECORDED IN CX(I,J) AS 2 IS RECORDED IN  00001565
             C                    STX(INS) AS -(X*100+J)-1000000.                    00001570
 0100          210 IF (ISTEP.EQ.0) GO TO 225                                        00001580
 0101          215 PRINT 220,NOD                                                    00001590
 0102          220 FORMAT ('0',// 6X,'NODE NUMBER',I5/)                             00001600
             C     **************UPDATE CX(I,J) FOR BRO***************************  00001610
             C                    BRO IS THE RIGHT BRANCHING VARIABLE                00001615
 0103          225 LX=BRO                                                           00001620
```

*Relevant to the TIMET Subroutine

```
0104          IX=LX/100                                                      00001630
0105          JX=LX-IX*100                                                   00001640
0106          CX(IX,JX)=2                                                    00001650
0107          KT2(JX)=KT2(JX)+1                                              00001660
0108          FIX(JX)=0                                                      00001720
0109          LQ1=LQ1-1                                                      00001725
0110          IF (KT2(JX).LT.(M-1)) GO TO 270                                00001730
0111          DO 255 I=1,M                                                   00001740
0112             IF (CX(I,JX).EQ.2) GO TO 255                                00001750
0113             CX(I,JX)=1                                                  00001760
0114             NSX=NSX+1                                                   00001763
0115             STX(NSX)=   (I*100+JX)+1000000                              00001766
0116             FIX(JX)=1                                                   00001770
0117             LQ1=LQ1+1                                                   00001780
0118             FIXI(JX)=I                                                  00001790
0119             GO TO 270                                                   00001800
0120      255 CONTINUE                                                       00001810
0121      270 LQ2=0                                                          00001820
0122          LR2=0                                                          00001825
0123          GO TO 283                                                      00001830
0124      272 IF (ISTEP.EQ.0) GO TO 276                                      00001840
0125          PRINT 220,NOD                                                  00001850
        C     **************UPDATE CX(I,J) FOR BR1************************** 00001853
        C                    BR1 IS THE LEFT BRANCHING VARIABLE              00001856
0126      276 LQ2=0                                                          00001860
0127          LR2=0                                                          00001866
0128          LX=BR1                                                         00001870
0129          IX=LX/100                                                      00001875
0130          JX=LX-IX*100                                                   00001880
0131          CX(IX,JX)=1                                                    00001885
0132          FIX(JX)=1                                                      00001890
0133          LQ1=LQ1+1                                                      00001892
0134          DO 279 I=1,M                                                   00001895
0135             IF (IX.EQ.I) GO TO 281                                      00001897
0136      279 CONTINUE                                                       00001900
0137      281 FIXI(JX)=IX                                                    00001902
0138      283 IF (ISTEP.NE.2) GO TO 300                                      00001905
0139      285 DO 295 I=1,M                                                   00001910
0140             PRINT 290, I,(CX(I,J),J=1,N)                                00001920
0141      290    FORMAT (/5X,'CX(I,J)',4X,'I=',I3,2X, 20I4/23X, 20I4)         00001930
0142      295 CONTINUE                                                       00001940
0143          PRINT 297,(FIX(J),J=1,N)                                       00001950
0144      297 FORMAT (/5X,'FIX(J)',12X, 20I4/23X, 20I4)                      00001960
        C     **************APPLY CAPACITY RULE****************************** 00001970
        C                    AND UPDATE CX(I,J) AND STX(INS).                00001980
0145      300 IF (IUNCAP.EQ.1) GO TO 2300                                    00002010
0146      305 IF (ICAPR.EQ.0) GO TO 2300                                     00002020
0147      310 DO 2000 K=1,P                                                  00002030
        C                    FIND THE SUM OF MINIMUM D(I,J,K) OVER EACH J FOR A   00002040
        C                    GIVEN K, I.E., MINSD= SUM OF MIND(J)            00002050
0148          MINSD=0                                                        00002060
0149          DO 900 J=1,N                                                   00002070
0150             IF(FIX(J).EQ.0) GO TO 350                                   00002080
        C                    IF  FIX(J)=1, SET MIND(J)=D(I,J,K) FOR CX(I,J)=1  00002090
        C                    AND MOVE TO NEXT COLUMN J                       00002100
0151          INDI=FIXI(J)                                                   00002110
0152          MIND(J)=D(INDI,J,K)                                            00002120
0153          GO TO 800                                                      00002130
```

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FORTRAN IV G LEVEL  21                   MAIN               DATE = 80206          14/35/07

0154          350    LK=0                                                          00002160
0155                 I=1                                                           00002170
0156                 MIND(J)=D(I,J,K)                                              00002180
            C                    SKIP D(I,J,K) WHEN CX(I,J)=2 & MOVE TO NEXT ROW I  00002190
0157          400    IF(CX(I,J).EQ.2) GO TO 600                                    00002200
0158          500    IF(D(I,J,K).LT.MIND(J)) MIND(J)=D(I,J,K)                      00002210
0159                 GO TO 700                                                     00002220
0160          600    LK=LK+1                                                       00002230
0161                 IF(I.GT.LK) GO TO 700                                         00002240
0162                 I=I+1                                                         00002250
0163                 MIND(J)=D(I,J,K)                                              00002260
0164                 GO TO 750                                                     00002270
0165          700    I=I+1                                                         00002280
0166          750    IF(I.LE.M) GO TO 400                                          00002290
0167          800    MINSD=MINSD+MIND(J)                                           00002300
0168          900 CONTINUE                                                         00002310
0169          910 IF (ISTEP.NE.2) GO TO 980                                        00002320
0170                 PRINT 950, K, MINSD,(MIND(J),J=1,N)                           00002330
0171          950    FORMAT('0','K, MINSD,(MIND(J),J=1,N)',10I10)                  00002340
            C                    FIND BALANCE AVAILABLE CAPACITY IBALD FOR A GIVEN K 00002350
            C                    IF IBALD IS NEGATIVE, THEN BACKTRACK.              00002360
0172          980    IBALD=S(K)-MINSD                                              00002380
0173         1000 IF (IBALD.LT.0) GO TO 6200                                       00002390
0174              DO 1500 J=1,N                                                    00002400
            C                    SKIP COLUMN J IF FIX(J)=1                          00002410
0175                 IF (FIX(J).EQ.1) GO TO 1500                                   00002420
0176              DO 1300 I=1,M                                                    00002430
            C                    SKIP ROW I IF CX(I,J)=2                            00002440
0177         1100    IF(CX(I,J).EQ.2) GO TO 1300                                   00002450
            C                    COMPUTE DIFFERENCE BETWEEN D(I,J,K) AND MIND(J).   00002470
            C                    IF IT IS MORE THAN AVAILABE BALANCE, SET CX(I,J)=2 00002480
0178         1200    IDIFD=D(I,J,K)-MIND(J)                                        00002490
0179                 IF ((IDIFD-IBALD).LE.0)  GO TO 1300                           00002510
0180                 CX(I,J)=2                                                     00002520
0181                 NSX=NSX+1                                                     00002523
0182                 STX(NSX)=-(I*100+J)-1000000                                   00002526
            C                    LQ2 COUNTS THE NUMBER OF CX(I,J) VALUES SET EQUAL  00002530
            C                    TO 2 IN A CYCLE                                    00002540
0183                 LQ2=LQ2+1                                                     00002550
            C                    KT2(J) KEEPS AN ACCOUNT OF CX(I,J) VALUES SET EQUAL 00002560
            C                    TO 2 FOR COLUMN J                                  00002570
0184                 KT2(J)=KT2(J)+1                                               00002580
            C                    FOR COLUMN J, IF ALL BUT ONE CX(I,J) VALUES ARE    00002590
            C                    EQUAL TO 2, SET THAT CX(I,J)=1 &  SET FIX(J)=1     00002600
0185                 IF(KT2(J).LT.(M-1)) GO TO 1300                                00002610
0186              DO 1250 LR=1,M                                                   00002620
0187                 IF(CX(LR,J).EQ.2) GO TO 1250                                  00002630
0188                 CX(LR,J)=1                                                    00002640
0189                 NSX=NSX+1                                                     00002643
0190                 STX(NSX)=   (LR*100+J)+1000000                                00002646
0191                 FIX(J)=1                                                      00002650
            C                    LQ1 KEEPS AN ACCOUNT OF COLUMNS FOR WHICH FIX(J)=1 00002655
0192                 LQ1=LQ1+1                                                     00002660
            C                    FIXI(J) SPECIFIES INDEX I FOR WHICH FIX(J)=1       00002662
0193                 FIXI(J)=LR                                                    00002665
0194                 GO TO 1500                                                    00002670
0195         1250 CONTINUE                                                         00002680
0196         1300 CONTINUE                                                         00002690
```

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FORTRAN IV G LEVEL  21                    MAIN                DATE = 80206          14/35/07

  0197        1500 CONTINUE                                                          00002700
  0198        1800 IF (ISTEP.NE.2) GO TO 2000                                        00002710
  0199             PRINT 1900, K, LQ2, LQ1                                           00002720
  0200        1900 FORMAT ('0','K=',I3,'  LQ2=',I3, '  LQ1=', I3)                    00002730
  0201             DO 1930 I=1,M                                                     00002740
  0202                PRINT 290, I,(CX(I,J),J=1,N)                                   00002750
  0203        1930 CONTINUE                                                          00002770
  0204             PRINT 297,  (FIX(J),J=1,N)                                        00002780
  0205        2000 CONTINUE                                                          00002800
             C                         A CYCLE EXAMINES ALL THE FACILITIES.          00002803
             C                         IF IN A CYCLE, THE CAPACITY RULE RESULTS IN SETTING 00002810
             C                         ADDITIONAL CX(I,J) VALUES EQUAL TO 2, THEN REPEAT   00002820
             C                         THE CYCLE. BUT IF FIX(J)=1 FOR ALL J, THEN DO NOT   00002830
             C                         REPEAT THE CYCLE.                             00002835
  0206             IF (LQ1.EQ.N) GO TO 2300                                          00002840
  0207             IF (LQ2.EQ.LR2) GO TO 2300                                        00002845
  0208        2200 LR2=LQ2                                                           00002860
  0209             GO TO 300                                                         00002870
             C     **************SOLVE (LAGRANGIAN) RELAXED PROBLEM**************    00002880
             C                         FIND FLB(K) -- VECTOR OF FACILIES FOR COMPUTING     00002890
             C                         C(I,J) MATRIX & LOWER BOUND. IT HAS VALUE 1 IF A    00002900
             C                         FACILITY IS USED, OTHERWISE IT HAS 0 VALUE.   00002910
  0210        2300 DO 2500 K=1,P                                                     00002920
  0211                FLB(K)=0                                                       00002930
  0212        2500 CONTINUE                                                          00002940
  0213             DO 3000 J=1,N                                                     00002950
  0214                IF (FIX(J).EQ.0) GO TO 3000                                    00002960
  0215                INDI=FIXI(J)                                                   00002970
  0216             DO 2550 K=1,P                                                     00002990
  0217                IF (E(INDI,K).EQ.0) GO TO 2550                                 00003000
  0218                IF (FLB(K).EQ.1) GO TO 2550                                    00003010
  0219                FLB(K)=1                                                       00003020
  0220        2550 CONTINUE                                                          00003030
  0221        3000 CONTINUE                                                          00003060
  0222             IF (ISTEP.NE.2) GO TO 3150                                        00003070
  0223             PRINT 3100, (FLB(K),K=1,P)                                        00003080
  0224        3100 FORMAT('0','(FLB(K),K=1,P)   ',  20I4/16X,20I4)                   00003090
             C                         COMPUTE COST MATRIX C(I,J) FOR THE RELAXED PROBLEM  00003100
  0225        3150 DO 3400 J=1,N                                                     00003110
  0226             DO 3300 I=1,M                                                     00003120
  0227                BSUM=0.0                                                       00003130
  0228             DO 3200 K=1,P                                                     00003140
  0229                IF (FLB(K).EQ.1) GO TO 3200                                    00003150
  0230                IF (E(I,K).EQ.0) GO TO 3200                                    00003160
  0231                BSUM=BSUM+(B(K) * (FLOAT(D(I,J,K))/ FLOAT(S(K))))              00003170
  0232        3200 CONTINUE                                                          00003180
  0233        3250    C(I,J)=A(I,J)+BSUM                                             00003190
  0234        3300 CONTINUE                                                          00003200
  0235        3400 CONTINUE                                                          00003210
  0236             IF (ISTEP.NE.2) GO TO 3445                                        00003220
  0237             DO 3430 I=1,M                                                     00003230
  0238                PRINT 3420, I, (C(I,J),J=1,N)                                  00003250
  0239        3420    FORMAT (/5X, 'C(I,J)',5X, 'I=', I3,2X, 5F15.4,                 00003260
                 1             6(/23X, 5F15.4))                                      00003265
  0240        3430 CONTINUE                                                          00003270
             C                         FIND SUM OF MINIMUM C(I,J) VALUES OVER EACH J,      00003290
             C                         I.E., MINSC=SUM OF MINC(J).                   00003300
             C                         IF FIX(J)=1, THEN MINC(J)=C(I,J) WHERE CX(I,J)=1    00003310
```

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FORTRAN IV G LEVEL  21                 MAIN               DATE = 80206          14/35/07

 0241          3445 MINSC=0.0                                                      00003320
 0242               DO 3900 J=1,N                                                  00003340
 0243                  IF (FIX(J).EQ.0) GO TO 3500                                 00003350
 0244                  INDI=FIXI(J)                                                00003360
 0245                  MINC(J)=C(INDI,J)                                           00003370
 0246                  SOLX(J)=INDI                                                00003380
 0247                  GO TO 3850                                                  00003410
 0248          3500    LK=0                                                        00003430
 0249                  I=1                                                         00003440
              C                   SKIP C(I,J) ELEMENT IF CX(I,J)=2 & MOVE TO NEXT I 00003470
 0250          3550    IF (CX(I,J).EQ.2) GO TO 3700                                00003480
 0251                  IF ((I-LK).EQ.1) GO TO 3600                                 00003485
 0252                  IF (C(I,J).GE.MINC(J)) GO TO 3750                           00003490
 0253          3600    MINC(J)=C(I,J)                                              00003500
 0254                  IMIN=I                                                      00003510
 0255                  GO TO 3750                                                  00003520
 0256          3700    LK=LK+1                                                     00003530
 0257          3750    I=I+1                                                       00003590
 0258          3800    IF (I.LE.M) GO TO 3550                                      00003600
 0259                  SOLX(J)=IMIN                                                00003610
 0260          3850    MINSC=MINSC+MINC(J)                                         00003620
 0261          3900 CONTINUE                                                       00003630
 0262               IF (ISTEP.NE.2) GO TO 3940                                     00003640
 0263               DO 3920 J=1,N                                                  00003650
 0264                  PRINT 3910, J,MINC(J),SOLX(J)                               00003660
 0265          3910 FORMAT ('0','J,MINC(J),SOLX(J)', I5,F15.4,I6)                  00003670
 0266          3920 CONTINUE                                                       00003680
              C                   COMPUTE FIXED COST FC FOR LOWER BOUND            00003710
 0267          3940 FC=0                                                           00003720
 0268               DO 4000 K=1,P                                                  00003730
 0269                  IF (FLB(K).EQ.0) GO TO 4000                                 00003740
 0270          3950    FC=FC+B(K)                                                  00003750
 0271          4000 CONTINUE                                                       00003760
              C     **************COMPUTE LOWER BOUND LOWB************************ 00003770
 0272          4050 LOWB=MINSC+FC                                                  00003780
 0273               IF (ISTEP.EQ.0) GO TO 4150                                     00003790
 0274               PRINT 4120, MINSC, FC, LOWB                                    00003800
 0275          4120 FORMAT ('0',' MINSC, FC, LOWB ', F15.4, I15, F15.4)            00003810
              C                   COMPARE LOWER BOUND WITH BEST UPPER BOUND STAR   00003820
              C                   BUBS WHICH EQUALS BUB/(1+EPS). IF LOWB IS        00003830
              C                   GREATER THAN OR EQUAL TO BUBS, THEN BACKTRACK    00003840
 0276          4150 IF (LOWB.GE.BUBS)GO TO 6200                                    00003850
              C                   CHECK IF CURRENT SOLUTION SATISFIES CAPACITY     00003880
              C                   CONSTRAINTS                                      00003890
 0277          4200 IF (IUNCAP.EQ.1) GO TO 4420                                    00003900
 0278          4210 DO 4400 K=1,P                                                  00003910
 0279                  NSUMD=0                                                     00003920
 0280               DO 4300 J=1,N                                                  00003930
 0281                  IX=SOLX(J)                                                  00003950
 0282                  NSUMD=NSUMD+D(IX,J, K)                                      00003960
 0283          4300 CONTINUE                                                       00003970
 0284               IF (ISTEP.NE.2) GO TO 4320                                     00003980
 0285                  PRINT 4310, K,NSUMD                                         00003990
 0286          4310    FORMAT ('0', 'K,NSUMD',2I10)                                00004000
 0287          4320    IF(NSUMD.LE.S(K)) GO TO 4400                                00004010
 0288                  GO TO 5100                                                  00004020
 0289          4400 CONTINUE                                                       00004030
              C     **************COMPUTE UPPER BOUND UPB IF CAPACITY CONSTRAINTS  00004040
```

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FORTRAN IV G LEVEL  21                  MAIN              DATE = 80206         14/35/07
                 C                    ARE SATISFIED.                                          00004050
                 C                    UPB=SUM OF A(I,J)+FIXED COST FCUB BASED ON              00004060
                 C                    SOLUTION VECTOR SOLX(J)                                 00004070
                 C                    VECTOR OF FACILITIES FOR UPPER BOUND FUB(K) HAS         00004080
                 C                    VALUES 1 OR 0 BASED ON FACITILY USED OR OTHERWISE       00004090
  0290            4420 DO 4450 K=1,P                                                          00004100
  0291                    FUB(K)=0                                                            00004110
  0292            4450 CONTINUE                                                               00004120
  0293                 NSUMA=0                                                                00004130
  0294                 FCUB=0                                                                 00004140
  0295            4500 DO 4650 J=1,N                                                          00004150
  0296                    IX=SOLX(J)                                                          00004170
  0297                    NSUMA=NSUMA+A(IX,J)                                                 00004180
  0298            4550 DO 4600 K=1,P                                                          00004190
  0299                    IF(E(IX,K).EQ.0) GO TO 4600                                         00004200
  0300                    IF(FUB(K).EQ.1) GO TO 4600                                          00004210
  0301                    FUB(K)=1                                                            00004220
  0302                    FCUB=FCUB+B(K)                                                      00004230
  0303            4600 CONTINUE                                                               00004240
  0304            4650 CONTINUE                                                               00004250
  0305                 IF (ISTEP.NE.2) GO TO 4700                                             00004260
  0306                 PRINT 4660, (FUB(K),K=1,P)                                             00004270
  0307            4660 FORMAT('0','(FUB(K),K=1,P)  ',  20I4/16X,20I4)                         00004280
  0308            4700 UPB=NSUMA+FCUB                                                         00004290
  0309            4708 IF (ISTEP.EQ.0) GO TO 4750                                             00004300
  0310                 PRINT 4710, NSUMA, FCUB, UPB, BUB, BUBS                                00004310
  0311            4710 FORMAT('0','NSUMA, FCUB, UPB, BUB, BUBS ',2I10, 3F15.4)                00004320
                 C                    COMPARE UPPER BOUND WITH BEST UPPER BOUND               00004330
                 C                    IF UPB IS LESS THAN BUB, SET IT AS BUB AND              00004340
                 C                    NOTE THE SOLUTION                                       00004350
  0312            4750 IF (UPB.GE.BUB) GO TO 5100                                             00004360
  0313            4770 BUB=UPB                                                                00004370
  0314                 BUBS= BUB/ (1.0+EPS)                                                   00004380
  0315                 IBNOD=NOD                                                              00004385
  0316                 DO 4800 J=1,N                                                          00004390
  0317            4800 BSOLX(J)=SOLX(J)                                                       00004400
  0318                 DO 4850 K=1,P                                                          00004410
  0319            4850 BSOLY(K)=FUB(K)                                                        00004420
                 C     **************COMPARE LOWB WITH BUBS. IF LOWB IS GREATER               00004430
                 C                    THAN OR EQUAL TO BUBS, THEN BACKTRACK                   00004440
  0320            4900 IF (LOWB.GE.BUBS)GO TO 6200                                            00004450
                 C     **************IF FIX(J) VALUES ARE 1 FOR EACH J, THEN BACKTRACK        00004480
  0321            5100 IF (LQ1.EQ.N) GO TO 6200                                               00004500
                 C     **************APPLY THE BOUNDING RULE**************************        00004510
                 C                    IF THE DIFFERENCE BETWEEN C(I,J) AND MINC(J) IS         00004515
                 C                    GREATER THAN THE DIFFERENCE BETWEEN BUBS AND            00004520
                 C                    LOWB, THEN CX(I,J)=2                                    00004525
                 C     **************APPLY BRANCHING RULE AND FIND BR1, THE NEXT              00004530
                 C                    VARIABLE FOR LEFT BRANCHING.                            00004540
                 C                    FIND NMINC(J), THE NEXT HIGHER VALUE THAN MINC(J)       00004550
                 C                    AND DIFBR(J), THE DIFFERENCE BETWEEN THEM.              00004555
  0322                 DBOUND=BUBS-LOWB                                                       00004568
  0323            5200 DO 5250 J=1,N                                                          00004570
  0324                    NMINC(J)=0.0                                                        00004580
  0325                    DIFBR(J)=0.0                                                        00004590
  0326            5250 CONTINUE                                                               00004600
  0327                 DO 5600 J=1,N                                                          00004610
                 C                    SKIP TO NEXT J IF FIX(J)=1                              00004620
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FORTRAN IV G LEVEL  21                  MAIN              DATE = 80206          14/35/07

 0328                   IF (FIX(J).EQ.1) GO TO 5600                                      00004630
 0329                   LK=0                                                             00004640
 0330                   I=1                                                              00004650
             C                      SKIP C(I,J) IF CX(I,J)=2 & MOVE TO NEXT I            00004670
 0331         5300      IF (CX(I,J).EQ.2) GO TO 5350                                     00004680
 0332                   IF (I.EQ.SOLX(J)) GO TO 5350                                     00004690
 0333                   IF ((C(I,J)-MINC(J)).GT.DBOUND) GO TO 5330                       00004700
 0334                   IF ((I-LK).EQ.1) GO TO 5320                                      00004710
 0335                   IF (C(I,J).GE.NMINC(J)) GO TO 5400                               00004720
 0336         5320      NMINC(J)=C(I,J)                                                  00004730
 0337                   GO TO 5400                                                       00004735
 0338         5330      CX(I,J)=2                                                        00004740
 0339                   NSX=NSX+1                                                        00004742
 0340                   STX(NSX)=-(I*100+J)-1000000                                      00004745
 0341                   KT2(J)=KT2(J)+1                                                  00004747
 0342                   IF(KT2(J).LT.(M-1)) GO TO 5350                                   00004750
 0343                   INDI=SOLX(J)                                                     00004752
 0344                   CX(INDI,J)=1                                                     00004755
 0345                   NSX=NSX+1                                                        00004758
 0346                   STX(NSX)= (INDI*100+J)+1000000                                   00004760
 0347                   FIX(J)=1                                                         00004762
 0348                   LQ1=LQ1+1                                                        00004764
 0349                   FIXI(J)=INDI                                                     00004766
 0350                   GO TO 5600                                                       00004768
 0351         5350      LK=LK+1                                                          00004770
 0352         5400      I=I+1                                                            00004775
 0353                   IF(I.LE.M) GO TO 5300                                            00004780
 0354         5500      DIFBR(J)=NMINC(J)-MINC(J)                                        00004785
 0355         5600 CONTINUE                                                              00004790
 0356              IF (ISTEP.NE.2) GO TO 5650                                            00004795
 0357              DO 5620 I=1,M                                                         00004820
 0358                   PRINT 290, I,(CX(I,J),J=1,N)                                     00004830
 0359         5620 CONTINUE                                                              00004850
 0360              PRINT 297,  (FIX(J),J=1,N)                                            00004860
             C                      IF FIX(J)=1 FOR ALL J, THEN BACKTRACK.               00004880
 0361         5650 IF (LQ1.EQ.N) GO TO 6200                                              00004890
             C                      FIND MAXDIF, THE MAXIMUM DIFFERENCE DIFBR(J)         00004900
 0362              LF=0                                                                  00004905
 0363              DO 5800 J=1,N                                                         00004910
 0364                   IF (FIX(J).EQ.1) GO TO 5690                                      00004915
 0365                   IF ((J-LF).EQ.1) GO TO 5660                                      00004920
 0366                   IF (DIFBR(J).LT.MAXDIF) GO TO 5800                               00004925
 0367         5660      MAXDIF=DIFBR(J)                                                  00004930
 0368                   LJ=J                                                             00004935
 0369                   GO TO 5800                                                       00004940
 0370         5690 LF=LF+1                                                               00004943
 0371         5800 CONTINUE                                                              00004946
 0372              IF (ISTEP.NE.2) GO TO 5840                                            00004950
 0373              DO 5820 J=1,N                                                         00004953
 0374                   IF (FIX(J).EQ.1) GO TO 5820                                      00004956
 0375                   PRINT 5810, J, NMINC(J), MINC(J), DIFBR(J)                       00004960
 0376         5810 FORMAT ('0','J,NMINC(J),MINC(J),DIFBR(J)', I5,3F15.4)                 00004963
 0377         5820 CONTINUE                                                              00004966
             C     ***************BRANCHING VARIABLE BR1 CORRESPONDS TO MAXDIF*****      00004970
 0378         5840 DO 5900 J=1,N                                                         00004980
 0379                   IF (J.NE.LJ) GO TO 5900                                          00004990
 0380         5850      BR1=SOLX(J)*100+J                                                00005000
 0381              IF (ISTEP.EQ.0) GO TO 6020                                            00005010
```

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0382                PRINT 5880,  BR1                                              00005020
0383        5880    FORMAT('0',' BR1',I10)                                        00005030
0384                GO TO 6020                                                    00005040
0385        5900 CONTINUE                                                         00005050
           C       **************UPDATE STX(INS) AND NSX************************  00005060
           C                    NSX REPRESENTS THE NUMBER OF VARIABLES IN STX(INS) 00005070
0386        6020 NSX=NSX+1                                                        00005090
0387        6040 STX(NSX)=BR1                                                     00005100
0388             IF (ISTEP.NE.2) GO TO 6100                                       00005150
0389             PRINT 6088, (STX(INS), INS=1,NSX)                                00005160
0390        6088 FORMAT('0',' STX(INS)', 10I10, 122(/, 10X,10I10))                00005170
           C       **************MOVE TO THE NEXT (LEFT BRANCH) NODE AND APPLY    00005220
           C                    CAPACITY RULE                                     00005230
0391        6100 NOD=NOD+1                                                        00005240
0392        6110 IF (ET.EQ.0.0) GO TO 6150                                        00005242*
0393             IF(INSET.EQ.1) GO TO 6147                                        00005244*
0394             IF (INET.EQ.1) GO TO 6150                                        00005246*
0395             CALL TIMET(INT)                                                  00005248*
0396             ELTN=(INT-ITO)*26.04E-6                                          00005250*
0397             IF (ELTN.LT.ET) GO TO 6150                                       00005253*
0398        6120 PRINT 6125, NOD, ELTN, BUB, BUBS, IBNOD                          00005256*
0399        6125 FORMAT ('0', 'WAS AT NODE',I6, ' AT ELAPSED TIME =', F10.4,      00005260*
               1          ' SECONDS.',/1X, '  BUB=',F15.4, '  BUBS=',F15.4,       00005263*
               2          '  AT NODE=',I7)                                        00005266*
0400             IBUB=BUB                                                         00005267*
0401             IF (IBUB.EQ.9999999) GO TO 6146                                  00005268*
0402        6130 PRINT 6135, (BSOLX(J),J=1,N)                                     00005270*
0403        6135 FORMAT('0', 'SOLUTION CORRESPONDING TO BUB IS',  //1X,           00005273*
               1          '(BSOLX(J), J=1,N)',10I8,3(/18X,10I8))                  00005276*
0404        6140 PRINT 6145, (BSOLY(K), K=1,P)                                    00005280*
0405        6145 FORMAT(/1X,'(BSOLY(K), K=1,P)',10I8,2(/18X, 10I8))               00005290*
0406        6146 INET=1                                                           00005292*
0407             INIS=ISTEP                                                       00005294*
0408             INSET=1                                                          00005296*
0409             ISTEP=2                                                          00005298*
0410             GO TO 6150                                                       00005300*
0411        6147 ISTEP=INIS                                                       00005302*
0412             INSET=0                                                          00005304*
0413        6150 GO TO 272                                                        00005306
           C       ***************END IF AT THE ROOT NODE*************************** 00005308
0414        6200 IF (NSX.EQ.0) GO TO 8100                                         00005310
0415        6220 IF ( IABS(STX(NSX)).GT.1000000) GO TO 6500                       00005320
0416        6250 BRO=STX(NSX)                                                     00005330
0417        6270 STX(NSX)=-BRO-1000000                                            00005340
0418             IF (ISTEP.EQ.0) GO TO 6308                                       00005390
0419             PRINT 6305,  BRO                                                 00005400
0420        6305 FORMAT('0', 'BRO  ',I10)                                         00005410
0421        6308 IF (ISTEP.NE.2) GO TO 6330                                       00005420
0422             PRINT 6088, (STX(INS), INS=1,NSX)                                00005430
           C       **************MOVE TO THE NEXT (RIGHT BRANCH) NODE AND APPLY   00005490
           C                    CAPACITY RULE                                     00005500
0423        6330 NOD=NOD+1                                                        00005510
0424        6410 IF (ET.EQ.0.0) GO TO 6450                                        00005512*
0425             IF (INSET.EQ.1) GO TO 6445                                       00005516*
0426             IF (INET.EQ.1) GO TO 6450                                        00005518*
0427             CALL TIMET(INT)                                                  00005520*
0428             ELTN=(INT-ITO)*26.04E-6                                          00005523*
0429             IF (ELTN.LT.ET) GO TO 6450                                       00005526*
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*Relevant to the TIMET Subroutine

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FORTRAN IV G LEVEL  21                MAIN              DATE = 80206          14/35/07

 0430          6420 PRINT 6125, NOD, ELTN, BUB, BUBS, IBNOD                          00005528*
 0431               IBUB=BUB                                                         00005530*
 0432               IF (IBUB.EQ.9999999) GO TO 6442                                  00005532*
 0433          6430 PRINT 6135, (BSOLX(J),J=1,N)                                     00005533*
 0434          6440 PRINT 6145, (BSOLY(K), K=1,P)                                    00005536*
 0435          6442 INET=1                                                           00005538*
 0436               INIS=ISTEP                                                       00005540*
 0437               INSET=1                                                          00005542*
 0438               ISTEP=2                                                          00005544*
 0439               GO TO 6450                                                       00005546*
 0440          6445 ISTEP=INIS                                                       00005548*
 0441               INSET=0                                                          00005550*
 0442          6450 GO TO 210                                                        00005552
 0443          6500 IF ( STX(NSX).GT.1000000) GO TO 6520                             00005555
 0444               LX=-STX(NSX)-1000000                                             00005560
 0445               IX=LX/100                                                        00005570
 0446               JX=LX-IX*100                                                     00005580
 0447               CX(IX,JX)=0                                                      00005590
 0448               KT2(JX)=KT2(JX)-1                                                00005595
 0449               GO TO 6550                                                       00005600
 0450          6520 LX= STX(NSX)-1000000                                             00005610
 0451               IX=LX/100                                                        00005620
 0452               JX=LX-IX*100                                                     00005630
 0453               CX(IX,JX)=0                                                      00005640
 0454               FIX(JX)=0                                                        00005650
 0455               LQ1=LQ1-1                                                        00005660
 0456          6550 NSX=NSX-1                                                        00005690
 0457               GO TO 6200                                                       00005700
             C      **************PRINT THE OUTPUT*********************************  00005730
 0458          8100 IBUB=BUB                                                         00005740
 0459               CALL TIMET(IT1)                                                  00005750*
 0460               ELT1=(IT1-IT0)*26.04E-6                                          00005760*
 0461               PRINT 8105, ELT1                                                 00005770*
 0462          8105 FORMAT ('0',///1X, 'ELAPSED TIME IN SECONDS=', F15.8)            00005780*
 0463               PRINT 8120, NOD                                                  00005790
 0464          8120 FORMAT ( '0','TOTAL NUMBER OF NODES EXPLORED =',I3)              00005800
 0465               IF (IBUB.EQ.9999999) GO TO 8350                                  00005810
 0466          8130 PRINT 8150                                                       00005820
 0467          8150 FORMAT ('0', 'NOTE: 1.  FOLLOWING X(I,J) VARIABLES SHOW DESIGN', 00005830
                   1        ' I TO WHICH ACTIVITY J IS ASSIGNED FOR J=1 TO N.',      00005840
                   2        /7X, '2.  IF EPSILON EPS WAS ASSIGNED A POSITIVE',       00005850
                   3        ' (NON-ZERO) VALUE, THE SOLUTION MAY BE SUBOPTIMAL.',/)  00005860
 0468          8180 PRINT 8200, (BSOLX(J),J=1,N)                                     00005870
 0469          8200 FORMAT('0',T55,  'OPTIMAL SOLUTION',/1X,T55,                     00005880
                   1        '----------------',//1X, 'X(I,J) WITH VALUE 1:',10I8,    00005890
                   2        3(/,21X,10I8))                                           00005900
 0470          8220 PRINT 8250, (BSOLY(K), K=1,P)                                    00005910
 0471          8250 FORMAT ('0',      'Y(K) VALUES:', 8X, 10I8, 2(/,21X,10I8))       00005920
 0472          8280 PRINT 8300,IBUB                                                  00005930
 0473          8300 FORMAT ('0',  'OPTIMAL VALUE OF OBJECTIVE FUNCTION:', I15///)    00005940
 0474               GO TO 8500                                                       00005950
 0475          8350 PRINT 8400                                                       00005960
 0476          8400 FORMAT ('0', ' PROBLEM DOES NOT HAVE A FEASIBLE SOLUTION',       00005970
                   1        /1X,     ' BECAUSE THE CAPACITY CONSTRAINTS CANNOT',     00005980
                   2        /1X, ' BE SATISFIED.',/)                                 00005990
 0477          8500 PRINT 8550                                                       00006000
 0478          8550 FORMAT ('0','*****NORMAL END OF JOB*****',/)                     00006010
 0479          8600 STOP                                                             00006020
 0480               END                                                              00006030
```

*Relevant to the TIMET Subroutine

APPENDIX B

DICTIONARY OF ZIPCAP SYMBOLIC NAMES

SYMBOLIC NAME	DEFINITION
A(I,J)	VARIABLE COST OF ACTIVITY J USING DESIGN I
B(K)	FIXED COST OF FACILITY K
BRO	BRANCHING VARIABLE WITH VALUE 0, I.E., RIGHT-BRANCH VARIABLE X(I,J)
BR1	BRANCHING VARIABLE WITH VALUE 1, I.E., LEFT-BRANCH VARIABLE X(I,J)
BSOLX(J)	CURRENT BEST SOLUTION CONTAINING X(I,J) VARIABLES
BSOLY(K)	CURRENT BEST SOLUTION CONTAINING Y(K) VARIABLES
BSUM	B(K) * D(I, J, K)/S(K) SUMMED OVER APPLICABLE K
BUB	BEST UPPER BOUND
BUBS	BEST UPPER BOUND IF SOLUTION MAY BE SUBOPTIMAL WITHIN EPS. BUBS = BUB/(1 + EPS)
C(I,J)	COST ELEMENTS FOR THE RELAXED PROBLEM
CX(I,J)	CONTAINS FIXED AND FREE X(I,J) VARIABLES. FIXED VARIABLES ARE ASSIGNED A VALUE OF 1 OR 2, AND FREE VARIABLES ARE ASSIGNED A VALUE 0. A VALUE OF 1 IMPLIES THAT THAT PARTICULAR X(I,J) HAS A VALUE 1, AND FIX(J) IS FIXED AS 1. A VALUE OF 2 IMPLIES THAT THAT PARTICULAR VARIABLE SHOULD NOT BE CONSIDERED FOR CURRENT COMPUTATIONS CX(I,J) IS UPDATED BY THE CAPACITY RULE, THE BOUNDING RULE, AND THE RULES FOR BRANCHING AND BACKTRACKING
D(I,J,K)	CAPACITY REQUIRED AT FACILITY K FOR ACTIVITY J WHEN ACTIVITY J USES DESIGN I
DBOUND	DIFFERENCE BETWEEN BOUNDS BUBS AND LOWB
DIFBR(J)	DIFFERENCE IN C(I,J) VALUES FOR SELECTING BRANCHING VARIABLE
E(I,K)	HAS VALUE 1 IF DESIGN I USES FACILITY K, OTHERWISE THE VALUE IS 0
ELT1	ELAPSED TIME IN SECONDS TO EXECUTE THE PROGRAM OBTAINED FROM THE TIMET SUBROUTINE

ELTN	ELAPSED TIME IN SECONDS TO COMPARE WITH ET IF SPECIFIED
EPS	EPSILON VALUE IF A SUBOPTIMAL SOLUTION ACCEPTABLE, E.G, EPS OF 0.002 IMPLIES THAT THE SOLUTION MAY BE SUBOPTIMAL, BUT IS GUARANTEED TO HAVE A VALUE WITHIN 0.2% OF THE OPTIMAL VALUE. EPS IS 0 IF AN OPTIMAL SOLUTION IS DESIRED
ET	ELAPSED TIME, IF SPECIFIED, AT WHICH THE NODE AND BOUNDS INFORMATION IS PRINTED
FC	FIXED COST FOR COMPUTING LOWER BOUND
FCUB	FIXED COST FOR COMPUTING UPPER BOUND
FIX(J)	VECTOR OF FIXED COLUMNS. A COLUMN IS FIXED IF IT HAS A FIXED X(I,J) VARIABLE WITH VALUE 1
FIXI(J)	VECTOR SPECIFYING INDEX I CORRESPONDING TO FIX(J) OF VALUE 1
FLB(K)	VECTOR OF FACILITIES FOR COMPUTING LOWER BOUND
FUB(K)	VECTOR OF FACILITIES FOR COMPUTING UPPER BOUND
I	INDEX FOR DESIGNS
IBALD	BALANCE AVAILABLE CAPACITY FOR A GIVEN FACILITY
IBNOD	NODE CORRESPONDING TO THE BEST UPPER BOUND
IBUB	BEST UPPER BOUND
ICAPR	OPTION TO USE CAPACITY RULE
IDIFD	DIFFERENCE BETWEEN A D(I,J,K) VALUE AND MIND(J)
IINPT	OPTION TO LIST INPUT DATA
IMIN	MINIMUM OVER INDEX I FOR A GIVEN COLUMN J
INET	INDICATOR FOR ET
INIS	HAS THE SAME VALUE AS ISTEP
INS	INDEX FOR STACK OF VARIABLES STX
INSET	INDEX FOR DISPLAYING DETAILED STEPS IF OPTION ET IS SPECIFIED
INT	INTERMEDIATE CALL TO TIMET SUBROUTINE

ISTEP	OPTION TO LIST SUMMARY OF INTERMEDIATE STEPS, DETAILED STEPS, OR TO SKIP THE LISTING
IT0	INITIAL CALL TO TIMET SUBROUTINE
IT1	FINAL CALL TO TIMET SUBROUTINE
IUNCAP	OPTION TO INDICATE IF THE PROBLEM BEING SOLVED IS CAPACITATED OR UNCAPACITATED
IX	INDEX I OF VARIABLE X(I,J)
J	INDEX FOR ACTIVITIES
JX	INDEX J OF VARIABLE X(I,J)
K	INDEX FOR FACILITIES
KT2(J)	A COUNTER FOR CX(I,J) VALUES SET EQUAL TO 2 FOR COLUMN J
LK	A COUNTER
LOWB	LOWER BOUND
LQ1	A COUNTER FOR CX(I,J) VALUES SET EQUAL TO 1
LQ2	A COUNTER FOR CX(I,J) VALUES SET EQUAL TO 2 IN A CYCLE IN WHICH ALL THE FACILITIES ARE EXAMINED
LR2	A COUNTER SET EQUAL TO LQ2 AT THE END OF A CYCLE WHEN APPLYING THE CAPACITY RULE
P	NUMBER OF FACILITIES
S(K)	TOTAL CAPACITY OF FACILITY K
SOLX(J)	SOLUTION SHOWING INDEX 1 OF X(I,J) VARIABLES CORRESPONDING TO J=1, 2, ..., N
STX(INS)	STACK OF FIXED X(I,J) VARIABLES FOR BRANCHING AND BACK-TRACKING. AN X(I,J) RECORDED IN CX(I,J) AS 1 DUE TO THE BRANCHING RULE IS RECORDED IN STX(INS) AS X * 100 + J . AN X(I,J) RECORDED IN CX(I,J) AS 1 DUE TO THE CAPACITY RULE OR THE BOUNDING RULE IS RECORDED IN STX(INS) AS (X * 100 + J) + 1,000,000. AN X(I,J) RECORDED IN CX(I,J) AS 2 IS RECORDED IN STX(INS) AS -(X * 100 + J) - 1,000,000
TIMET	A SUBROUTINE FROM THE PL1 LIBRARY TO RECORD THE EXECUTION TIME

UPB	UPPER BOUND
ZIPCAP	NAME OF THE PROGRAM, AN ACRONYM FOR ZERO-ONE INTEGER PROGRAM TO SOLVE MULTIACTIVITY MULTIFACILITY CAPACITY-CONSTRAINED ASSIGNMENT PROBLEMS

APPENDIX C

ANNOTATED OUTPUT FOR TEST PROBLEM 1

OPTIONS SELECTED : IINPT=1 ICAPR=1 ISTEP=1 IUNCAP=0 EPS= 0.0 ET= 0.0

(a)

INPUT DATA

NUMBER OF DESIGNS (M)= 3

NUMBER OF ACTIVITIES (N)= 4

NUMBER OF FACILITIES (P)= 5

(b)

VARIABLE COST MATRIX A(I,J)

I= 1	9847	15718	4450	8925
I= 2	10192	10542	4422	8118
I= 3	11019	9750	4609	8337

FIXED COST VECTOR B(K)

1750	2000	1750	1350	1000

CAPACITY LIMIT VECTOR S(K)

(c)

400	400	1000	400	400

CAPACITY USAGE MATRIX D(I,J,K)

K= 1

I= 1	0	0	0	0
I= 2	186	60	261	148
I= 3	154	38	175	100

K= 2

I= 1	0	0	0	0
I= 2	0	0	0	0
I= 3	154	38	175	100

K= 3

I= 1	525	144	1011	396
I= 2	186	60	261	148
I= 3	154	38	175	100

K= 4

I= 1	0	0	0	0
I= 2	0	0	0	0
I= 3	154	38	175	100

c

K= 5

I= 1	0	0	0	0
I= 2	186	60	261	148
I= 3	154	38	175	100

DESIGN-FACILITY MATRIX E(I,K)

I= 1	0	0	1	0	0
I= 2	1	0	1	0	1
I= 3	1	1	1	1	1

SUMMARY OF STEPS

MINSC, FC, LOWB	37229.3594	0	37229.3594
BR1	101		

d

```
     NODE NUMBER    2

 MINSC, FC, LOWB      35528.3633          1750     37278.3633
 BR1       203

     NODE NUMBER    3

 MINSC, FC, LOWB      32356.0000          7850     40206.0000
NSUMA, FCUB, UPB, BUB, BUBS      32356      7850     40206.0000   9999999.0000   9999999.0000
BRO         203

     NODE NUMBER    4

 MINSC, FC, LOWB      32324.0000          7850     40174.0000
NSUMA, FCUB, UPB, BUB, BUBS      32324      7850     40174.0000     40206.0000     40206.0000
BRO         101

     NODE NUMBER    5

 MINSC, FC, LOWB      33476.0000          7850     41326.0000


ELAPSED TIME IN SECONDS=     0.06226163
TOTAL NUMBER OF NODES EXPLORED =  5
NOTE: 1.  FOLLOWING X(I,J) VARIABLES SHOW DESIGN I TO WHICH ACTIVITY J IS ASSIGNED FOR J=1 TO N.
      2.  IF EPSILON EPS WAS ASSIGNED A POSITIVE (NON-ZERO) VALUE, THE SOLUTION MAY BE SUBOPTIMAL.

                                   OPTIMAL SOLUTION

X(I,J) WITH VALUE 1:       1      3      3      2
Y(K) VALUES:               1      1      1      1      1
OPTIMAL VALUE OF OBJECTIVE FUNCTION:         40174


*****NORMAL END OF JOB*****
```

d

e

f

g

APPENDIX D

ANNOTATED OUTPUT FOR TEST PROBLEM 2

OPTIONS SELECTED : IINPT=1 ICAPR=1 ISTEP=0 IUNCAP=0 EPS= 0.00200 ET= 0.0

(a)

INPUT DATA

NUMBER OF DESIGNS (M)= 5
NUMBER OF ACTIVITIES (N)= 4
NUMBER OF FACILITIES (P)= 8

(b)

VARIABLE COST MATRIX A(I,J)

I= 1	194951	218871	155094	104056
I= 2	235277	272087	143264	138641
I= 3	196138	220718	160399	107481
I= 4	198751	224042	167046	112445
I= 5	190873	229169	128361	112498

FIXED COST VECTOR B(K)

(c)

14000	14000	14000	14000	14000	28000	19000	31000

CAPACITY LIMIT VECTOR S(K)

350	350	350	200	200	700	500	800

CAPACITY USAGE MATRIX D(I,J,K)

K= 1

I= 1	80	90	100	180
I= 2	0	0	0	0
I= 3	80	90	100	180
I= 4	40	30	50	120
I= 5	0	0	0	0
K= 2				
I= 1	80	90	100	180
I= 2	0	0	0	0
I= 3	80	90	100	180
I= 4	40	30	50	120
I= 5	0	0	0	0
K= 3				
I= 1	80	90	100	180
I= 2	0	0	0	0
I= 3	80	90	100	180
I= 4	40	30	50	120
I= 5	0	0	0	0
K= 4				
I= 1	80	90	100	180
I= 2	0	0	0	0
I= 3	80	90	100	180
I= 4	40	30	50	120
I= 5	80	90	100	180
K= 5				
I= 1	80	90	100	180
I= 2	0	0	0	0
I= 3	80	90	100	180

(c)

I= 4	40	30	50	120
I= 5	80	90	100	180

K= 6

I= 1	240	180	300	450
I= 2	0	0	0	0
I= 3	120	90	150	360
I= 4	0	0	0	0
I= 5	40	30	50	120

K= 7

I= 1	160	180	200	360
I= 2	0	0	0	0
I= 3	80	60	100	240
I= 4	0	0	0	0
I= 5	160	180	200	360

K= 8

I= 1	200	150	250	600
I= 2	40	30	50	180
I= 3	0	0	0	0
I= 4	0	0	0	0
I= 5	120	90	150	300

DESIGN-FACILITY MATRIX E(I,K)

I= 1	1	1	1	1	1	1	1	1
I= 2	0	0	0	0	0	0	0	1
I= 3	1	1	1	1	1	1	1	0
I= 4	1	1	1	1	1	0	0	0

```
I= 5        0      0      0      1      1      1      1      1

ELAPSED TIME IN SECONDS=     0.09392625                                    (e)

TOTAL NUMBER OF NODES EXPLORED = 11                                        (f)

NOTE: 1.  FOLLOWING X(I,J) VARIABLES SHOW DESIGN I TO WHICH ACTIVITY J IS ASSIGNED FOR J=1 TO N.
      2.  IF EPSILON EPS WAS ASSIGNED A POSITIVE (NON-ZERO) VALUE, THE SOLUTION MAY BE SUBOPTIMAL.

                                OPTIMAL SOLUTION

X(I,J) WITH VALUE 1:      4    4    2    4

Y(K) VALUES:              1    1    1    1    1    0    0    1             (g)

OPTIMAL VALUE OF OBJECTIVE FUNCTION:        779502


*****NORMAL END OF JOB*****
```

APPENDIX E

ANNOTATED OUTPUT FOR TEST PROBLEM 3

OPTIONS SELECTED : IINPT=1 ICAPR=0 ISTEP=0 IUNCAP=1 EPS= 0.0 ET= 30.000

(a)

INPUT DATA

NUMBER OF DESIGNS (M)= 10
NUMBER OF ACTIVITIES (N)= 8
NUMBER OF FACILITIES (P)= 8

(b)

VARIABLE COST MATRIX A(I,J)

I= 1	21	13	20	8	15	10	35	20
I= 2	26	13	27	14	17	13	40	25
I= 3	25	12	26	13	16	12	20	23
I= 4	23	9	22	20	19	20	50	19
I= 5	23	20	24	13	20	15	40	17
I= 6	23	20	24	13	20	15	40	17
I= 7	26	13	26	20	15	15	35	20
I= 8	30	20	40	23	30	20	55	25
I= 9	26	13	26	20	20	15	40	15
I= 10	36	46	46	50	19	20	40	20

(c)

FIXED COST VECTOR B(K)

10	8	4	10	14	30	20	50

CAPACITY LIMIT VECTOR S(K)

8	8	8	8	8	8	8	8

CAPACITY USAGE MATRIX D(I,J,K)

K= 1

I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	1	1	1	1	1	1	1	1
I= 5	1	1	1	1	1	1	1	1
I= 6	1	1	1	1	1	1	1	1
I= 7	1	1	1	1	1	1	1	1
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	1	1	1	1	1	1	1	1

K= 2

I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	1	1	1	1	1	1	1	1

(c)

I= 5	1	1	1	1	1	1	1	1
I= 6	1	1	1	1	1	1	1	1
I= 7	1	1	1	1	1	1	1	1
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	1	1	1	1	1	1	1	1
K= 3								
I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	0	0	0	0	0	0	0	0
I= 5	1	1	1	1	1	1	1	1
I= 6	1	1	1	1	1	1	1	1
I= 7	1	1	1	1	1	1	1	1
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	1	1	1	1	1	1	1	1
K= 4								
I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	0	0	0	0	0	0	0	0

c

I= 4	1	1	1	1	1	1	1	1
I= 5	0	0	0	0	0	0	0	0
I= 6	0	0	0	0	0	0	0	0
I= 7	1	1	1	1	1	1	1	1
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	1	1	1	1	1	1	1	1
K= 5								
I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	0	0	0	0	0	0	0	0
I= 5	0	0	0	0	0	0	0	0
I= 6	0	0	0	0	0	0	0	0
I= 7	1	1	1	1	1	1	1	1
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	1	1	1	1	1	1	1	1
K= 6								
I= 1	1	1	1	1	1	1	1	1

c

I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	1	1	1	1	1	1	1	1
I= 5	1	1	1	1	1	1	1	1
I= 6	1	1	1	1	1	1	1	1
I= 7	0	0	0	0	0	0	0	0
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	0	0	0	0	0	0	0	0
K= 7								
I= 1	1	1	1	1	1	1	1	1
I= 2	0	0	0	0	0	0	0	0
I= 3	0	0	0	0	0	0	0	0
I= 4	1	1	1	1	1	1	1	1
I= 5	1	1	1	1	1	1	1	1
I= 6	0	0	0	0	0	0	0	0
I= 7	0	0	0	0	0	0	0	0
I= 8	0	0	0	0	0	0	0	0
I= 9	1	1	1	1	1	1	1	1
I= 10	0	0	0	0	0	0	0	0
K= 8								

I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	1	1
I= 3	1	1	1	1	1	1	1	1
I= 4	1	1	1	1	1	1	1	1
I= 5	1	1	1	1	1	1	1	1
I= 6	1	1	1	1	1	1	1	1
I= 7	1	1	1	1	1	1	1	1
I= 8	1	1	1	1	1	1	1	1
I= 9	0	0	0	0	0	0	0	0
I= 10	0	0	0	0	0	0	0	0

DESIGN-FACILITY MATRIX E(I,K)

I= 1	1	1	1	1	1	1	1	1
I= 2	1	1	1	1	1	1	0	1
I= 3	1	1	1	0	1	1	0	1
I= 4	1	1	0	1	0	1	1	1
I= 5	1	1	1	0	0	1	1	1
I= 6	1	1	1	0	0	1	0	1
I= 7	1	1	1	1	1	0	0	1
I= 8	0	0	0	0	0	0	0	1
I= 9	1	1	1	1	1	1	1	0
I= 10	1	1	1	1	1	0	0	0

```
ELAPSED TIME IN SECONDS=     0.57446837                                        (e)

TOTAL NUMBER OF NODES EXPLORED = 35                                            (f)

NOTE: 1.  FOLLOWING X(I,J) VARIABLES SHOW DESIGN I TO WHICH ACTIVITY J IS ASSIGNED FOR J=1 TO N.
      2.  IF EPSILON EPS WAS ASSIGNED A POSITIVE (NON-ZERO) VALUE, THE SOLUTION MAY BE SUBOPTIMAL.

                                        OPTIMAL SOLUTION
                                        ----------------

X(I,J) WITH VALUF 1:        6     3     6     3     3     3     3     6        (g)

Y(K) VALUES:                1     1     1     0     1     1     0     1

OPTIMAL VALUE OF OBJECTIVE FUNCTION:        253


*****NORMAL END OF JOB*****
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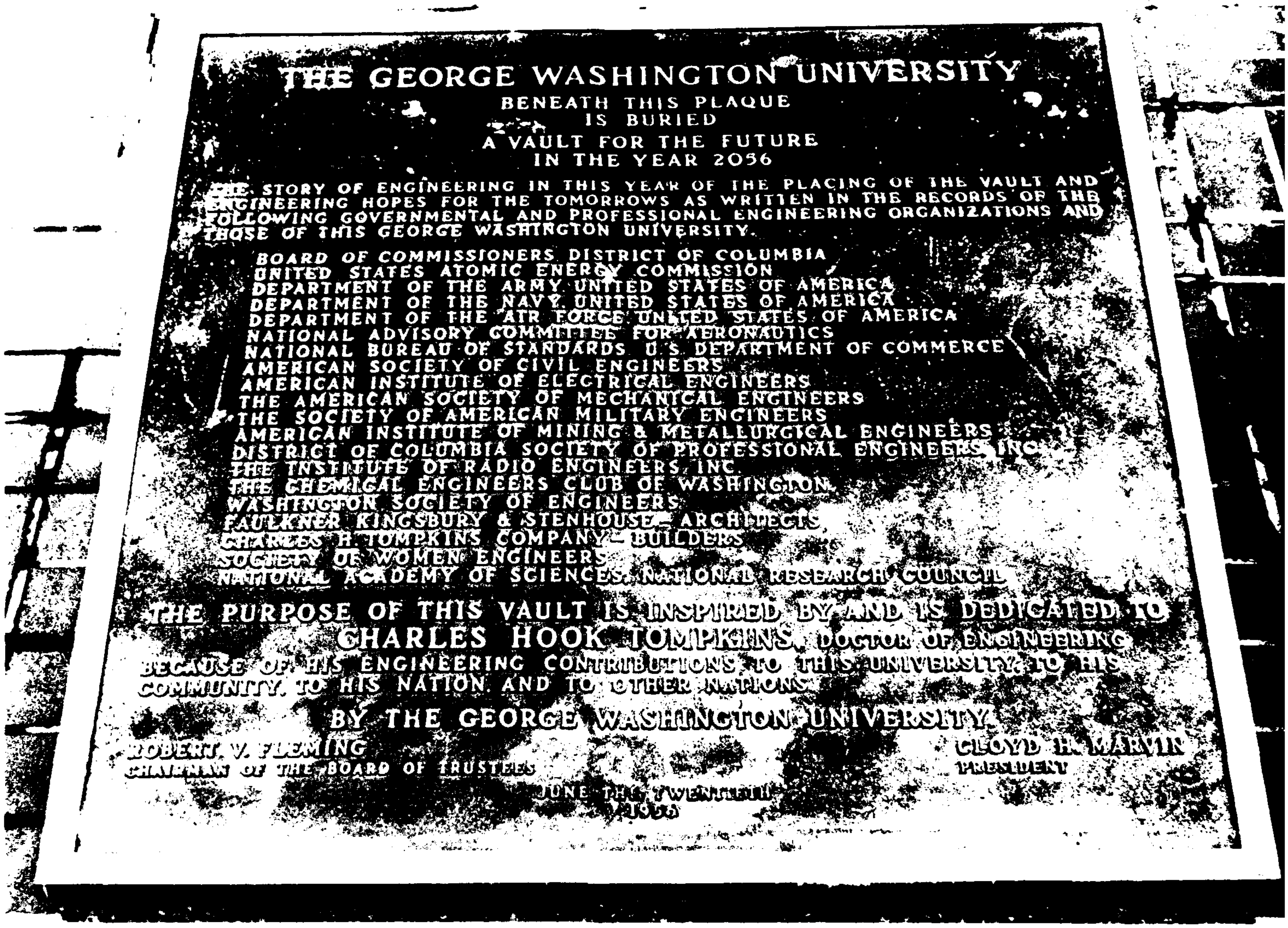
Wesleyan University

Prof Jacob Wolfowitz
University of South Florida

Prof Max A. Woodbury
Duke University



To cope with the expanding technology, our society must be assured of a continuing supply of rigorously trained and educated engineers. The School of Engineering and Applied Science is completely committed to this objective.

8